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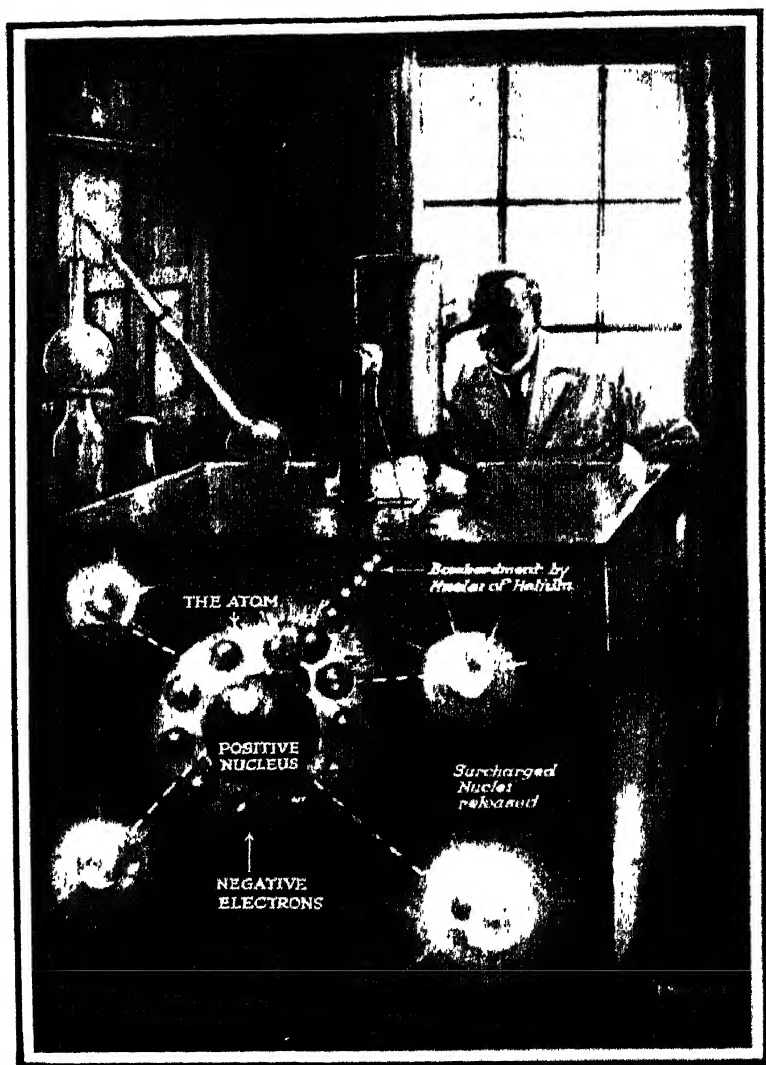
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CHEMISTRY OF TO-DAY

THE MYSTERIES OF CHEMISTRY LUCIDLY
EXPLAINED IN A POPULAR & INTERESTING
MANNER FREE FROM ALL TECHNICALITIES
AND FORMULÆ

BY

P. G. BULL, M.A. (OXON)

WITH OVER 150 ILLUSTRATIONS & DIAGRAMS

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INTRODUCTION

THIS book is not in any sense a textbook, but is an attempt to give some account of the less abstruse facts of Modern Chemistry in popular language and free entirely from all technical terms, so that it may be understood by all. It is a companion volume of an excellent series of books on Popular Science, and the issue of works of this kind is a sign of the times in which we live.

Years ago popular scientific knowledge was at a very low ebb indeed. The general Public, buried in abysmal ignorance, took little interest in scientific matters, and remained indifferent to all the wonderful happenings around them, and this for several reasons.

With the exception of the big Public Schools and the Universities, the teaching of Science was entirely ignored. It formed no part of the ordinary curriculum of the day. Even under the best conditions the time devoted to it was reduced to a minimum, and facilities for practical work were quite inadequate. How different are the conditions to-day !

Then, too, in those unenlightened days, the Public, believing that men of science were a race apart, speaking a jargon of their own, and dry-as-dust interpreters of the Scientific Thought of their time, were effectually frightened off. It is true that here and there some adventurous souls with their courage in their hands took down sometimes from dusty shelves some scientific volume and tried to unlock

the Door leading into the Unknown Land. For a brief moment there were Visions of interest and beauty, but obscured in a maze of technicalities and scientific verbiage. The book was returned to the shelf. The Door was shut with a bang. The Professors of this or that branch of Science were on their high pedestals, self-contained and exclusive. The whole atmosphere as far as the Public was concerned was entirely inimical to any Spirit of Inquiry; it was cold, repellent.

Then, one day, two significant things happened. Someone was found bold enough to take pen and paper and write a book on Popular Science in a style at once easy and attractive, and in language understood of the People. It fell into the hands of an equally bold and enterprising Publisher who saw which way the wind was blowing. Then, too, the learned men came down from their high seats and were not disinclined to impart some of their information to their less fortunate brethren. They, too, would write popular books, give lectures to the Public and to working men especially, on Saturday evenings, persuade the British Association to give popular addresses—were ready in fact with a Message for the Man in the Street. And the Public pricked up its ears. Tidings of great discoveries and inventions were in the air. It attended freely the lectures and addresses. It was minded to listen. Even the working man put on his Sunday coat and went off on a Saturday evening to hear a lecture on the Moon or the wonders of the Telephone. And what a Message it was when we consider but the happenings of the last few years!

Röntgen peering into our very flesh and bones, treating bodies wholly opaque as though they were transparent; Marconi bridging continents and seas with his wireless messages; the Curies electrifying the world with their

discovery of Radium ; Dewar converting air and other gases into the liquid and solid form, probing the depths of unimaginable cold ; Thomson with his remarkable researches on the Discharge of Electricity through Gases, wresting from Matter the Secret of the Atom ; Ramsay with his discovery of terrestrial Helium and other Rare Gases of the atmosphere ; Lodge investigating the nature of the " Ether of Space " ; Einstein juggling with Space and Time, introducing into our preconceived notions his profound and far-reaching Theory of Relativity ; Lowell reading in the face of Mars signs of a life other than our own ; and many others.

To-day the earnest seeker after knowledge is indeed fortunate. Popular books on every branch of Scientific Thought and Inquiry are open to him ; lectures, addresses, and libraries are given to him freely ; magazines, journals, and the Daily Press come to his aid with attractive articles ; Universities dot the land ; Technical Schools are springing up everywhere. What excuse is there to-day for a lack of knowledge (alas, still existent) of the rudiments, even, of Science ? The age in which we are living is admittedly a very wonderful one. The stupendous discoveries of the last few years, and the advance of scientific knowledge as the result of modern research, cannot surely be any longer a matter of indifference to any educated and thoughtful man or woman.

In the case of Chemistry, its onward march and progress has not been less rapid than that of any other branch of Pure and Applied Science. Since those far-off days of Lavoisier, when its foundations were well and truly laid, up to the present time, the advance has been rapid and unchecked. If we are to form any just conception of this progress we must extend our view of it into the uttermost

horizons of human life and activity. We no longer believe that Chemistry is bounded by any definite limits and frontiers, restrained by any narrow environment.

Modern Chemistry, especially in its numerous applications, knows no bounds or limitations. It embraces all conditions of modern life, and is profoundly associated with everything that makes for the advancement and welfare of the human race. Applied Chemistry in its relation to the Arts and Manufactures and to everything which affects our lives, has without doubt revolutionised the world. Every day something is added to the conveniences and amenities of life, as the result of Chemical Research.

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CONTENTS

CHAPTER I	
ALCHEMY AND THE DAWN OF CHEMISTRY	PAGE 13
CHAPTER II	
MATTER AND SOME OF ITS PROPERTIES—HOW THE CHEMIST REGARDS IT	21
CHAPTER III	
THE CHEMICAL ELEMENTS	32
CHAPTER IV	
CHEMICAL COMBINATION—HOW THE ELEMENTS COMBINE WITH ONE ANOTHER	41
CHAPTER V	
ATOMS AND MOLECULES: THE WORLD OF THE INFINITELY LITTLE	51
CHAPTER VI	
THE AIR WE BREATHE	60
CHAPTER VII	
CARBON DIOXIDE, CARBON MONOXIDE, AND THE RARE GASES OF THE ATMOSPHERE	73
CHAPTER VIII	
IN FROZEN WORLDS: MARVELS OF LOW TEMPERATURES . .	85
CHAPTER IX	
THE STORY OF FLAMES—COMBUSTION	95
CHAPTER X	
HYDROGEN AND ITS COMPOUNDS, SODIUM AND POTASSIUM .	106
CHAPTER XI	
A CLOSELY RELATED FAMILY—CHLORINE, BROMINE, IODINE, FLUORINE	118
CHAPTER XII	
SULPHUR—PHOSPHORUS—ARSENIC—ANTIMONY—BISMUTH .	127

CHAPTER XIII		PAGE
ELECTROLYSIS, OR THE DECOMPOSITION OF LIQUIDS BY THE ELECTRIC CURRENT		135
CHAPTER XIV		
ACIDS—BASES—SALTS—CRYSTALS		149
CHAPTER XV		
SOME METALS AND THEIR PROPERTIES		160
CHAPTER XVI		
THE ROMANCE OF RADIUM AND RADIOACTIVITY		167
CHAPTER XVII		
HOW THE ELEMENTS ARE CLASSIFIED		180
CHAPTER XVIII		
THE WONDERS OF THE SPECTROSCOPE		189
CHAPTER XIX		
WHAT THE SPECTROSCOPE TELLS US ABOUT THE SUN AND OTHER HEAVENLY BODIES		202
CHAPTER XX		
CARBON AND SOME OF ITS COMPOUNDS		218
CHAPTER XXI		
THE STORY OF CARBON COMPOUNDS (CONTINUED)		230
CHAPTER XXII		
CHEMISTRY IN DAILY LIFE		240
CHAPTER XXIII		
CHEMISTRY AND PLANT LIFE IN FIELD AND GARDEN		252
CHAPTER XXIV		
SOME ASPECTS OF INDUSTRIAL AND APPLIED CHEMISTRY		265
CHAPTER XXV		
RECENT DISCOVERIES AND APPLICATIONS		278
CHAPTER XXVI		
FURTHER DEVELOPMENTS OF MODERN RESEARCH		291
INDEX		306

LIST OF ILLUSTRATIONS

BOMBARDING THE ATOM	<i>Frontispiece</i>
AN ALCHEMIST'S LABORATORY	PACING PAGE 16
TRANSFORMATION OF CHEMICAL ENERGY	32
"SALVUS" BREATHING APPARATUS	64
HELIUM IN AIRSHIPS	80
(a) RÖNTGEN RAYS	128
(b) OPTOPHONE DISC	128
(c) ELECTRIC SPARK	128
(d) BACTERIA ON ROOT OF BEAN	128
WELDING BY ELECTRICITY	144
A SO-CALLED "PERPETUAL MOTION" MACHINE	176

COAL TAR DYES IN PHOTOGRAPHY	I
PRODUCTION OF DIAMONDS	224
CAPPING A "SPOUTER"	240
A LIVING FLY-TRAP	246
EXPLOSIVES IN TIME OF PEACE	272
LIQUID AIR AS AN EXPLOSIVE	288
THE OPTOPHONE	296
CUTTING METAL WITH THE OXY-ACETYLENE FLAME	304

CHEMISTRY OF TO-DAY

CHAPTER I

ALCHEMY AND THE DAWN OF CHEMISTRY

MODERN Chemistry, looking back through the long perspective of Time, is not only inclined to view the Alchemists of old with pious veneration, but it also, in the light of recent research, sees a fulfilment even of some of their theories and aspirations. And it is well to remember that many of these early pioneers were men of lofty ideas and of high intellect. They worked and toiled much, often in fields remote from chemical thought and inquiry. And beyond the material aspect of their labours, the quest for the one Basic Foundation of Matter, and the Transmutation of the Base Metals into Silver and Gold, there was ever before their eyes the Mystic aspect of the question. This was natural since Alchemy was concerned both with the Material and the Divine. Beyond the Material there were certain Philosophic Principles—the Divine Spirit or Essence, the “Soul of the World,” which pervaded all things. Also the “Spirit of the World” by which the Soul influenced the body and was bound to it.

The Alchemists, no doubt, were heartily abused for thus introducing into their practical work so much pious reflection and religious imagery; and we know that their inquiries often took them far afield into regions speculatively remote from their purely scientific work. At the same time we cannot help being struck by the beauty of some of their conceptions. They were in a great measure symbolic, of course, but they give us a glimpse of the high level to which

14 Alchemy & the Dawn of Chemistry

much of their thought attained. The Alchemists believed, so it has been thought by many, that the Material by purifications similar to chemical processes, might be gradually brought within the sphere of a Moral and Spiritual Regeneration. And just as the metals through successive stages of purification reached that highest plane of all, Perfect Silver and Perfect Gold, so, too, the Spirit of man might be redeemed from the gross material of Matter, and rise to a higher manifestation. Thus, beyond the material plane of Alchemy, there was ever the belief in the Progression towards the Divine.

If we look at Alchemy from the Material point of view, we shall find that it started with a theory of Creation involving the admission of a "First Matter," the base of all Creation. This was supposed to be derived from a "Hyle," or Foundation (*hulē* matter, Grk.), which entered into the structure of all material things. The four "Elements"—Earth, Air, Fire and Water—were associated with three Principles—Sulphur, Mercury and Salt. These by endless combination and differentiation gave rise to all the boundless variety of material substances.

There were seven metals known as forms of Matter—Copper, Gold, Iron, Lead, Silver, Tin and Zinc. It is also probable that the Alchemists were acquainted with Arsenic, Bismuth and Mercury. All these metals were considered to be stable, but this did not preclude the possibility of changing them from one into another.

The Alchemists believed that all material things were capable of infinite change; it was one of the chief tenets of their faith. Nor need we be surprised; changes were ever occurring around them in Nature. Physical agencies such as Light, Heat, etc., were always at work proving that Matter was not permanent. The exposure of metals to the air and moisture, producing rust and other effects due to chemical change, suggested often the question of Transmutation.

Not all the metals were considered to be of the same purity and excellence. By a gradual series of gradations

Alchemy & the Dawn of Chemistry 15

Gold and Silver at last emerged as the only Perfect ones. Into these it was sought to change all the others, and to this end all their efforts were directed. In season and out of season, the Alchemists laboured with their crude apparatus, their retorts and furnaces, towards the attainment of one great object—the Philosopher's Stone, the basis of all Transmutation. That they achieved some results even with their rough apparatus is known to-day. Their methods of manipulation were doubtless coarse and imperfect, but their labours were not entirely fruitless.

With regard to the question of Transmutation, if the Alchemists had been successful in changing base metals into gold and silver, we do not know what use their discovery would have been to the world at large. Modern research during the last few years has indicated the lines on which it would be necessary to proceed in order to bring about the change. The results, however, would be out of all proportion to the cost, and economic laws would soon prove the futility of such attempts.

As for the Philosopher's Stone, it, apparently, never materialised but ever remained a mere Abstraction.

The Alchemists, as we have already mentioned, were often subjected to much abuse and scathing criticism. Strained Analogies and far-fetched Allegories, which might mean something or nothing, completed the confusion into which mens' minds were thrown. The critics outside the fold of this occult Art passed heavy judgment upon the workers within.

Time, however, as is so often the case, has vindicated the truth of much that the Alchemists asserted and believed. Modern Research on the Constitution of Matter has profoundly affected the old ideas concerning material things. We believe to-day that there are Ultimate Particles or Electrons, atoms of Negative Electricity with a Positive Nucleus, which are the bricks of which the whole structural edifice of Matter is built. And if this be so, the Ancient Doctrine of one "Primordial Matter" or "First Matter"—the Protyle—is not the wild conception that it was once thought to be (chap. xxv).

16 Alchemy & the Dawn of Chemistry

So, too, with regard to Transmutation. "The Story of Radium" tells us (as we shall see in chap. xvi) that in certain cases the radioactive substances spontaneously change into other forms. The cherished dreams of the Alchemists have, in great measure, come true at last.

The science of Alchemy is of very ancient origin. From the Arabs came the term "Al-Chymy," the Chemistry, Al being the definite article. The Rabbis and Jewish scholars of the Hebrews no doubt handed down to later generations the old and Ancient Magic common to Chaldaea and Babylon. From Egypt, too, where at Alexandria the Sciences flourished and Magical Arts were practised, we may trace some sources of the science of so-called Al-Chymy or Alchemy. It was the object of study by sages and monks from as early as A.D. 720. Indeed, before the Christian Era investigation proves that Al-Chymy was not unknown even in those early days. In Mediæval days the Science was styled the "Hermetic Art," implying an origin from Hermes Trismegistus, an Egyptian teacher. In A.D. 730 lived the great Geber, a man of pious aspirations, full of belief in the Philosopher's Stone, the Elixir of Life and all that the Divine Art implies.

We have already stated that there is a Mystic or Religious side to Alchemy. An early writer puts it thus: "The practice of Alchymy enables us to understand, not merely the marvels of Nature, but also the nature of the Great Divine One Himself in His unspeakable glory"; and he goes on to show that the Art reveals, as in a mirror, the purification of Man from sin and the steps by which he may pass "before he can rise again to a new and higher life."

The idea of Transmutation was outside all this; the purely Material aspect (as we have seen) of the Art.

But as the baser metals gradually melted into the finer Gold, so also the Alchemists believed that Man in his spiritual state could by successive purifications attain to the higher and purer life of the Spirit; a Transmutation from a lower to a higher plane.

In this conception is involved the doctrine of the Unity of



By permission of the

AN ALCHEMIST'S LABORATORY

This is a photograph of the reconstructed alchemist's laboratory in the new German museum at Munich. The most prominent features are the furnaces and the fantastically shaped retorts for carrying on distillation.

Deutsches Museum, Munich

Alchemy & the Dawn of Chemistry 17

Nature and of all Natural Phenomena. As in plants and animals there is a gradual progression from the lowest to the highest—different degrees of Perfection—so, too, in all material things, in metals and the like, the Alchemists held that there might be seen different gradations of excellence. What nobler object, then, they argued, than to hasten the development of the lower to the higher, to exchange the dross for the Gold? And in the moral sphere of Man's personality, successive stages of purification, advances in Moral and Spiritual Perfection, would unite Man at last in the one great Unification of Nature, and so to Nature's God.

We may not, it is true, always agree with all the analogies drawn from Holy Writ, but the line of argument is pretty plain through Alchemical teaching, that Man could by casting off the Material seek Re-union with the God-head. Death would free him from the bonds of the Material world, whence he would pass to the Higher Plane. Finally, as in Buddhism (as exemplified in the Higher Teachings of the Buddha) he would be absorbed into the Great Rest. If this be so, there is a relation between Alchemy and Theosophy, so it is thought, the Western System of Philosophy uniting with the teachings of the East and especially with the exalted precepts of the Buddha. Indeed, it is claimed that there are distinct references to Alchemy in the ancient books of India. But on the whole the trend of Indian thought and Art leads rather in the direction of Re-incarnation and the influence of Mind upon Mind.

Alchemy was practised in China, so it appears, considerably before the Christian Era. In the teachings of the old philosophers there can be traced the belief in that wonderful Stone, the Stone of Wisdom, which was the basis of all Transmutation. But, the Mystery which shrouded it—nothing seems to have lifted that!

Dante in Canto X, "Paradiso," speaks of the Fourth Heaven where are seen the spirits of the Fathers and Theologians, many of whom were famous in the alchemical world, such as Roger Bacon, Pope John, etc. Mention is

18 Alchemy & the Dawn of Chemistry

made, also, of "Thomas of Aquinum," greatest of all the schoolmen. A disciple of the Dominicans in his early days, he afterwards became a Friar and studied at Cologne and Paris. A great theologian, he died early and was canonized by John XXII. His great work, the "Sum of Theology," is the acknowledged code of Latin Christianity.

In Canto XXIX, "Inferno," there is a reference to two Alchemists—Greffolino d'Arezzo and Capacchio :

"I of Arezzo was," one made reply,

"And Albert of Siena had me burned,"

and further :

"But unto the last Bolgia of the ten,

For Alchemy which in the world I practised,
Minos, who cannot err, has me condemned."

One of the most distinguished Alchemists was that early pioneer in scientific investigation, Roger Bacon. He was a long way ahead of his time and generation, for the age into which he was born was an ignorant one. But his learning and scientific knowledge shone as a beacon light pointing the way to true progress and casting a lurid glow upon the extravagant theories and crude ideas of the men of his time.

Bacon considered that in "Experimental Science lay the best means of checking the results obtained by mathematical processes." It led on to further researches in new fields of inquiry.

In a treatise styled, "On the Marvellous Power of Art and Nature," Bacon (referring to the discovery of gun-powder) mentions an explosive mixture "producing a noise like thunder and flashes like lightning."

And again : "From saltpetre and other ingredients we are able to make a fire that shall burn at any distance that we please."

In many ways Bacon curiously anticipated ideas held to-day by Modern Science. For instance, he says that radiant Force can proceed independently of man's power of perceiving it.

Is not Radiation invisible to our eyes? Its effects only

Alchemy & the Dawn of Chemistry 19

are seen. And somewhere else he dramatically states that "there are many dense bodies which altogether interfere with the visual and other senses of man, so that rays cannot pass with such energy so as to produce an effect on human senses. Yet, nevertheless, rays do really pass without our being aware of it." A wonderful forecast of X-rays!

As Clement IV the Pope became interested in Bacon's works and received from him his "*Opus Majus*," the "*Minus*" and the "*Opus Tertium*." Afterwards he was accused of sorcery, and his works were condemned. He died in 1292.

Many were the hardships and persecutions which the Alchemists suffered! In the reign of Henry IV Transmutation was actually made a felony. The act was, however, repealed. No doubt there were extravagant claims made which could not be substantiated, such as those of Transmutation and the Elixir of Life. Add to this the fantastic Imagery and the unintelligible language which obscured so much of their work and teaching like some dense fog. Who could penetrate it?

It will be seen in the next chapter that the doctrine of "Phlogiston," which asserted that Fire was one of the four primitive "elements," was held largely by the early chemists. When a body was heated a wonderful Essence or Principle entered into it. On cooling this Essence escaped. But discoveries by those later chemists—Priestley and Lavoisier—effectually killed these crude ideas. More advanced and correct explanations were given concerning the heating of bodies, and other phenomena. The Dawn of Modern Chemistry was dispelling the mists, and chasing away the fogs which hitherto had enshrouded the work of the early chemists and Alchemists.

The discovery of Oxygen gas by Priestley in 1774, and the later theories of Lavoisier in 1778, as to the true nature of combustion and the changes to which burning matter is subjected, swept away ere long the old notions and theories concerning "Phlogiston." It was seen now that when a

20 Alchemy & the Dawn of Chemistry

body lost some of this mysterious Essence during combustion, what really happened was this ; the body absorbed Oxygen from the air and combined with it—formed an Oxide, as we say. Later on Lavoisier introduced the first real System of Chemistry, collecting and co-ordinating all the known facts, and bringing some sort of Unity out of the chaos which had formerly prevailed.

CHAPTER II

MATTER AND SOME OF ITS PROPERTIES HOW THE CHEMIST REGARDS IT

SINCE Chemistry is concerned with the transformations and properties of material things, it may not be out of place to get a conception of some of the Properties of Matter, perhaps rather from the Physical point of view, before going on to look at it in the light of Chemical Science. At the same time we cannot say that Chemistry is separated by any sharp boundaries from this or that branch of Science which has to do with various kinds of Phenomena. We know that Chemistry often joins hands with other fields of enquiry which are sometimes thought to be outside its immediate scope. This is specially seen in later days, as in the investigation of the Properties of Radium. In this field many workers in different branches of Science have toiled.

The Greeks had a conception of Matter in the early days, which curiously enough closely resembled the general view held to-day. To the Greek philosopher Matter was composed of four different "Elements" or kinds of things—Earth, Air, Fire and Water.

Many things no doubt suggested this, such as the earth beneath their feet—"Mother Earth" with all its diversity of shape and form; the wind rustling the leaves of tree and shrub; the flickering flames of burning bodies; the ever-flowing rivers and streams.

If we cut out the third of these concepts, we fall into agreement with these ancient ideas. Do we not say that all Matter is divided into Solids, Liquids and Gases?

The idea of Fire entering into the composition of Matter

22 Matter & Some of its Properties

lingered long in the minds of men. The old theories of the ancients gave place gradually to the doctrine of "Phlogiston," which taught that a "Fiery Essence" permeated all the structure of material bodies capable of burning. It could be introduced into substances by heating them with some other bodies which had a full share and more of this mysterious Essence. Other principles were added to the general conception in order to prop up the Phlogiston Theory. But even these failed to sustain the worn-out doctrine which in the days of Lavoisier received its death-blow.

It is a general belief that all forms of Matter—solids, liquids and gases—consist of very minute particles which, wonderful to say, are ever in a state of perpetual motion.

As it would be natural to suppose, these little particles, which for the present we may call Atoms or Molecules (though later we shall have to define them more precisely), do not move with the same freedom in solids as in liquids and gases. If only we could look into the inner structure of Matter, we should probably find that in solids the little particles are in movement, no doubt, but in a very limited sphere of action. But all evidence points to the view that there is some movement going on, although our eyes cannot perceive it. The pencil we hold in our hand, the glass of the tumbler on our table, are not those quiet inert objects which they are popularly supposed to be. Within their hidden structure countless millions of agitating molecules travel backwards and forwards in ceaseless vibration. Experiment tells us that this is so. The fact that bodies expand when heated and contract when cooled supports this idea. So, too, the curious fact that metals, if placed in close juxta-position to one another, will gradually but surely come into mutual contact.

If we could look into the interior of liquids, we should find the same movement taking place, but naturally with more freedom. The forces binding the little particles together and tending to restrain their activity, are now relaxed in a great measure. The field of action is less restricted.

We are led to suppose this from the fact that liquids give

Matter ☉ Some of its Properties 23

off a vapour—evaporate as we say—more easily than solids. In metals, for instance, the transition from the solid to the liquid, and from the liquid to a state of vapour, requires far more heat than is required to boil some water in a kettle. In some liquids such as Ether, the particles are even less restrained. A drop on the hand soon vanishes—we call it a mobile, volatile fluid.

It is in gases, however, that there is found the greatest freedom of motion. What a wonderful sight it would be if only we could view with our eyes that jostling hustling crowd of countless myriads of flying atoms. It has been computed that there are at the ordinary pressure of the atmosphere about forty trillion molecules present in every cubic centimetre of a gas! They are ever flying about in their containing vessel, continually knocking up against each other in ceaseless collision, and then bounding off like billiard balls, both from each other and also from the sides of the vessel.

In a very light gas, like Hydrogen, the molecules move about more freely still than in the case of a heavy gas like Carbon Dioxide, whose density is very much greater. If the containing vessel be exhausted of air, the remaining particles will have a much wider sphere of action; they will not jostle each other so much. It is like a ballroom when a number of dancers have retired. The remainder move about more readily in the less restricted area.

In solids and liquids the particles are attracted to one another by very great forces. We call this Cohesion. If a substance like a bar of iron be broken asunder, it is impossible to join the two pieces together again unless they are welded together by heat. We cannot get the molecules into sufficiently close contact so that the forces of Cohesion may act upon them. That the power which holds molecules together is very great is seen in the case of soap-bubbles whose film, just before it breaks, is of extreme tenuity. And the well-known experiment of causing a needle to float upon the surface of water illustrates the same thing. The needle rests upon the film of water without breaking it.

24 Matter & Some of its Properties

Since the particles of Matter are in constant motion it is not surprising that all bodies are porous in some degree. There must be a free path for the particles, however small. And the density of bodies varies according as the pores are large or small. This was proved long ago by taking a metal ball, and after filling it with water, tightly closing it. When the ball was subjected to great pressure, little drops of water were seen to issue from the pores of the metal and cover the surface.

If a body were divided and sub-divided down to these minute little particles we have been considering, we should require about 100,000,000 of such molecules in order to render them visible under the highest power of a microscope.

There is no doubt, however, that Matter can be subdivided to an infinitesimal degree. The little motes of dust dancing in the rays of the sun when they strike through a window, the emanations from some perfumed body like musk which affect our sense of smell, the excessive thinness of a film of silver on forks and spoons, the "scent" from a hunted animal—all these are instances.

If the emanations from such a body as musk are anything like the molecules, for instance, in a gas like Hydrogen, they must consist of incredibly minute particles, for it is supposed that it would require more than two million of such particles to occupy the space of one twenty-fifth part of an inch.

In the year 1827 an Englishman called Brown claimed to have discovered, not these minute particles themselves, but their effects in liquids. When working with a microscope he observed that certain minute little bodies in a liquid appeared to be always moving restlessly about and describing a series of irregular motions (Fig. 1). Many reasons were brought forward in order to account for the phenomenon. These were ruled out by careful experiment. And to-day we know that the constant agitation is due to the presence of moving molecules themselves. They are the cause of the movement of the larger particles seen in the

microscope. It is their effects which we see. They themselves are beyond our ken. If once we admit that bodies are porous—that there is a degree of separation between the minute particles of Matter—we need not be surprised that bodies can be compressed or dilated. We can reduce their volume or extend it at our will.

Not all bodies, however, can be compressed alike; a piece of india-rubber is very compressible; so also a piece of cork; water and most liquids, only very slightly; metals are compressible to a considerable degree, as witness the

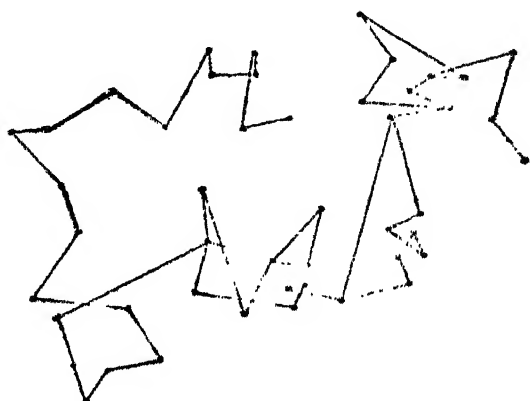


FIG. 1. IRREGULAR MOTIONS OF A PARTICLE IN A LIQUID.
Illustrating the Brownian movement. (After PERLH.)

coins in our pockets which are stamped with the head of the Sovereign and date of issue.

A remarkable application of the fact that water is slightly compressible is seen in what is known as "Wave-Transmission of Power." There has lately been exhibited in London an apparatus which cuts into granite like soap, and rivets steel plates at the rate of 2,400 blows a minute, by Messrs. Dorman and Co., Ltd., of Stafford.

It is claimed that water if placed in a pipe sealed at one end will yield to the impulse of a piston at the other end, and on the return stroke the water will expand elastically

26 Matter & Some of its Properties

to its original volume. If one end of the pipe were kept sealed and the piston continued to deliver fresh impulses very rapidly, the pressure would become so great that the pipe would burst. But instead of sealing one end, there is inserted a second piston which transmits the wave intensity or pressure to a motor, which utilises the energy in whatever form may be desired.

In the diagram (Fig. 2) we see what happens in the pipe. The piston A impinges on the column of water in the pipe P so rapidly and with such intensity that the liquid has no opportunity to recover its volume; waves are set up in quick succession, and their cumulative effect is brought to bear upon the piston B. The force in a pipe an inch in diameter is said to be terrific. Piston blows of 10 horse-



FIG. 2. WAVE TRANSMISSION OF POWER IN A PIPE
By permission of W. H. Dorman and Co.

power are delivered at the rate of 2400 a minute producing incredible pressure on the imprisoned column of water. The whole force of the waves or impulses can find no outlet except in driving the motor connected with the piston B. The equipment required for wave-transmission is inexpensive. Simplicity, adaptability, portability and other advantages are claimed by the inventors. In mining, shipping and shipbuilding, in general workshops and factories, for road and rail vehicles, in air-craft and other forms of application, its general use is confidently expected.

From what has been said about gases, we need not wonder at the fact that they are very compressible. Indeed, it is one of the Laws of gases which tells us that their volume varies according to the pressure applied. If, for instance, the pressure be doubled, then the volume of the gas will be reduced to one half. By repeatedly compressing air and

Matter & Some of its Properties 27

allowing it to escape, it may be reduced to a liquid state. If we were unable to compress air, all pneumatic tyres on bicycles and motors would become valueless at once.

If we cause a body to expand, we do the very opposite of compressing it. All solids, liquids and gases can be treated thus. A blacksmith, for instance, wishes to put an iron tyre on a wheel; when cold, the tyre cannot be fitted in a satisfactory manner. It is made just a little too small; when strongly heated it will, however, slip easily over the wheel, and on cooling down will bind it securely together. Experiments show that bridges are longer in summer than in winter. The little spaces left by engineers on a railway between the successive lengths of metal, are also an instance. If there were no room for expansion, the rails would be quickly put out of truth on a hot day. The rise and fall of the Mercury in a thermometer tells us that liquids expand and contract.

If a body which has expanded or has been compressed returns to its original state when allowed to do so, it is called Elastic.

Bodies exhibit this property in different degrees. The mainspring of a watch when coiled up is subjected all the time to a considerable strain accompanied by an internal force of stress. This tends to cause the spring to uncoil. This possesses Elasticity, therefore, to a considerable degree. If a ball be bounced on the ground it undergoes for a brief moment a change in its shape. But by reason of its Elasticity it quickly regains its usual form. That a ball behaves in this manner has been demonstrated thus: A billiard ball is allowed to drop from varying heights on a smooth hard surface covered with oil. At the point of contact the film of oil is found to be displaced to a greater or less extent dependent upon the distance through which the ball has fallen. An elegant example of the same thing is seen in soap bubbles: when floating in the air and allowed to settle on the arm, they will often bounce off and at the same time clearly reveal the distortion which for the moment affects their

28 Matter & Some of its Properties

shape. When it is considered how thin the film of a bubble is, its Elasticity is remarkable.

In speaking of the shape of bodies, it must be remembered that all must possess some external shape or form. And how boundless are the different shapes which Matter assumes! How infinite its variety of form! It is a far cry, perhaps, from the shape of the irregular stone which we pick up on the road side to those exquisite crystals of snow (Fig. 3) which are of extraordinary beauty and symmetry of arrangement, but it only proves the truth of what we are saying.

There is an interesting property of Matter which we must

now examine, for it is governed by important laws. It is the property which is characteristic of all bodies which are in a state of rest or uniform motion in a straight line. They continue to remain in this state unless they are influenced by external forces. According to this, if a body in motion were left to itself, entirely uninfluenced by anything outside it, it would con-



FIG. 3. SNOW CRYSTALS

tinue to move with a constant velocity. On the other hand it might be said that a body would continue to remain in a state of absolute rest if uninfluenced by external force. An application or two of these principles may be considered.

A carpenter hammers a nail into a board with two or three smart blows. If he were to try and push the nail in, he would be unable to do so. But the hammer moving with sharp quick strokes can easily overcome the resistance of the nail. At each impact its tendency is still to move onwards, and by reason of its Energy, it can do work. It drives the nail home. A man on a bicycle if he applies his brakes too hard,

Matter ☉ Some of its Properties 29

is liable to go over the handle-bars. A motor-car if stopped too suddenly illustrates the same thing. The people riding in the car will be pitched violently forward, and the fittings of the breaks will be dislocated. The bicycle and the car are governed by Laws which may not be broken.

We have used the term Energy above, and we must now look at it a little more closely. A definition of it would be, Capacity of doing Work. If a man lift a heavy weight from the ground, he may be said to have done Work. He has overcome the force of Gravity. This Work may be measured. If the weight be one Pound, the Work done is measured in terms of one Foot-Pound for every foot the weight is lifted. If a pound weight be lifted twenty feet, the Work done is represented by twenty Foot-Pounds.

There are two States or Conditions of Energy. In the one case, bodies are able to do Work because of the Power and Potentiality of Work which they possess. This is known as Potential Energy.

The weight of a clock before it is allowed to hang free is an instance. It is capable of doing work if you will let it. Directly it swings clear and begins slowly to descend, its Energy becomes changed into the second state which is called Kinetic Energy. The weight possesses Energy in virtue of its being in motion. All rapidly moving bodies are sources of such Energy. A shell rushing through the air at a speed of thousands of feet per second, and a bullet from a rifle are instances.

Energy is seen in various forms, such as the sun's rays, Mechanical Energy, Heat and Chemical Energy. And all these forms can be measured in terms of one another. Part of the Energy, for instance, in hitting a nail with a hammer is transformed into heat, and so we can take heat as our Unit of Measurement. This Unit is called a "Calorie." It is the amount of heat required to raise the temperature of one gramme of water from freezing point 0°C to 1°C .

The object of all transformation or conversion of Energy from one form into another is to do this with as little expenditure as possible. And it is here that the steam-

30 Matter & Some of its Properties

engine comes out badly ; only about one-eighth of the Fuel Energy being converted into Work. The loss from heat and friction is very great. And this is seen all through a cycle of transformations. The Energy of burning coal is transformed into that of motion in the engine, and hence into Electrical Energy and reconverted again into Mechanical Work. But always there is some Energy which is expended —on the wrong side of the balance sheet. The seekers after Perpetual Motion sooner or later fall into this trap. They produce a wonderful machine which in some cases continues in motion for quite a considerable time. But some of the Energy is converted into heat through friction (for frictionless it cannot be), and from whence can it be replenished ? Sooner or later the machine stops and to the inventor comes disillusion.

That there are illimitable sources of Energy as yet untapped we know to-day ; the difficulty is to utilize them. The Tides, the heat of the Sun, terrestrial heat, Radium with its gigantic stores of Energy locked up in the atom — all these are potential sources. That they will compete successfully with the energy desired from the combustion of Coal is improbable, as far as we know at present. Our daily food is a great source of Energy. Part of it is transformed into useful Work and again, as we saw above, part into heat. Our very muscles when they contract exhibit the transformation of their Potential into Kinetic Energy, producing Work and Heat. It has been calculated that over 30 per cent of the Energy is utilised as Work. If that be the case our muscles are more economical than the steam-engine whose output is about 10 per cent.

Energy together with Matter is indestructible. The products of a burning candle are exactly equal to the Hydrogen and Carbon of which the candle is composed, together with the Oxygen which has entered into combination with them. And so it is with Energy ; we may transform one state into another, but nothing is lost. We can see transformations going on around us every day of our lives. The total amount, however, in each case remains unchanged.

Matter & Some of its Properties 31

Although the chemist is not unconcerned with the purely physical characteristics of Matter, his attention is chiefly directed to those properties which are the result of chemical change. Matter is transformed in various ways, and the nature and variety of these transformations, together with the Laws which govern the resultant phenomena, are especially the object of his inquiry. At the same time, since Modern Chemistry has invaded every branch of Science, the chemist is bound to take into consideration those questions and inquiries which formerly belonged to the domain of pure Physics. The Science of Spectroscopy, for instance, to which we shall allude later on, is an instance of this. By physical means different kinds of Elements have been discovered and identified in the Sun and other heavenly bodies corresponding to those which it is the business of the chemist to investigate in his laboratory. And in his work concerning the transformation of Matter, the formation of new compounds and the analysis of old, the chemist is profoundly interested and concerned in those minute particles, the Atoms and Molecules which form the foundation of all material things. Of late years the researches in Radio-activity have revealed new and wonderful properties of the Ultimate Atoms of Matter unknown before. The dream of the Alchemists concerning Transmutation does not appear to be so vague after all. The ultimate constitution of Matter in which Chemistry and Physics join hands in exploring, though largely in the hands of investigators in the latter field of inquiry, concerns the chemist also. As fresh substances arise, they come within the scope of chemical investigation.

CHAPTER III

THE CHEMICAL ELEMENTS

THE modern view of the Chemical Elements dates from the time of Lavoisier. In 1789 he writes: "If we mean the last term in analysis, then every substance which we have not been able to decompose is for us an element, not that we can be certain that bodies which we regard as simple are not themselves composed of two or even a larger number of elements, but because these elements can never be separated, they act as elements."

The Greek concept of Matter which, as we have seen, involved the consideration of the so-called "elements"—Earth, Air, Fire and Water—suffered from one serious defect. It presented no objective reality to the minds of men. In their outlook on the material world the Greeks paid heed not so much to the diverse things of which the world was composed, as to certain properties and qualities of the things themselves. Thus a body was hot or cold, it was dry or wet.

To-day we look out on the world with clearer vision. We see, like the ancients of old, all the vast array of material substances of which the earth is composed, but we are able to arrange them all—solid, liquid and gaseous—into definite classes by chemical and physical means. We deal, in fact, with realities, and not with mere abstractions.

If we subject material things to chemical change and endeavour to decompose and break them up into simpler forms, we ultimately arrive at the simplest of all—bodies which we are not able to decompose into anything else. These ultimate bodies we call Elements. We include them all in one great class, and the rest of matter we put into

another, and call the bodies composing it Compounds. These by suitable means can be broken up and resolved into essentially different substances. Thus we cannot break up gold into any simpler body, and so we include it among the Elements. We can split up water, however, into its constituent parts, Oxygen and Hydrogen, two different bodies with different properties. But here the resolution ends. Oxygen and Hydrogen are therefore elements.

In the early days of Chemical Science, there were many bodies which were looked upon as Compounds. But we know to-day that they are really Elements. And this is very natural, for we possess apparatus and methods of working of a degree of refinement quite unknown to the early pioneers.

The element Chlorine was originally supposed to be a compound body containing Oxygen, and Scheele, its discoverer, called it Oxymuriatic Acid. But to-day we class it among the Elements. So, too, in the case of Potassium and Sodium. In the days of Lavoisier the relation between metals and their oxides gave rise to the supposition that there was some metallic element present in such oxides as Soda and Potash, and indeed in all the alkalis and alkaline earths. They were, however, classed among the Elements until Sir Humphry Davy in 1807 succeeded in decomposing first the alkali Potash into Potassium, Hydrogen and Oxygen, and next Soda into Sodium, Hydrogen and Oxygen, by means of the electric current. Later on, such bodies as Calcium, Strontium, Magnesium and Barium were added to the list, elements compelled to reveal themselves from their oxides, Lime, Strontia, Magnesia and Barytes, by more refined methods of working. And as time went on, other elementary bodies were added to the general list, until to-day we find that the number of active Elements is between eighty and ninety. A few years ago it was thought that we had come to an end of any further discoveries. Then a series of profound events convinced us of the folly of such belief. We arrived by successive steps of scientific inquiry at the dramatic discovery of such elements as Radium,

Thorium, Polonium, etc., new substances with new properties of a quite revolutionary order, flashed upon an unsuspecting world.

The Chemical Elements present to us such diverse degrees of properties and individual characteristics, and play such an important part in the economy of Nature and in our general life that, as far as this chapter is concerned, we can only look at them in a general way. We must reserve a closer acquaintance with them until later on.

Some of the Elements, such as Oxygen, Nitrogen, Chlorine and others are gases. Some exist in the liquid state like Bromine and Mercury. Others like Iron, Zinc, Lead, etc., are solids and are classed as metals. Some are widely distributed and occur in Nature in large quantities like Oxygen, Carbon, etc.; others are rare and little known such as Tellurium, Vanadium, Erbium and the like. All can be arranged and classified under one comprehensive scheme known as the Periodic System (Chap. xvii).

The Elements which enter into the composition of the earth do not number more than about a dozen substances, of which Oxygen, Silicon, Iron, Calcium, Aluminium and Sodium are the chief. Oxygen forms a large proportion of water by weight (eight-ninths) and Nitrogen four-fifths of atmospheric air by volume. Carbon enters into the composition of all living things. It also combines with other Elements to form an exceeding great number of compound substances. Some of the Elements such as Fluorine are very active; others like Argon and other rare gases are inert and very inactive.

Now, it would be very inconvenient in chemical work and investigation if we were compelled to represent the results in terms of the actual names of the Elements themselves. We must have some kind of abbreviated nomenclature in order to express our results with freedom. Thus it is that certain symbols have been adopted to represent the results of the interaction of the Elements with one another, and single letters, or at the most two, represent the names of individual elements. Thus we write O for Oxygen, N

for Nitrogen, H for Hydrogen. So, too, Cu for Copper and Bi for Bismuth. The origin of the names is often interesting.

Thus, Chlorine is derived from *Chlōros*: yellow-green (Grk.). In the words of Davy, "this is one of its obvious and characteristic properties." Hydrogen, the producer of water, is also derived from the Greek (*hudōr*: water; *gennaō*: produce). Ozone, too, from *Ozein*: to smell. Gallium and Germanium are named from French and German discoverers respectively. Some Elements are derived from Latin, such as Cu, Copper (*Cuprum*); Hg, Mercury (*Hydrargyrum*). Beryllium owes its name to Beryl, Potassium to Potash, Sodium to Soda (K and Na, Kalium and Natrium).

It is possible to divide the Elements into two broad groups—the Metals and the non-Metals. Iron, Zinc, Copper, Lead are included in the first group, and Oxygen, Sulphur, Phosphorus, etc. in the second. From a physical point of view the two groups differ much from each other. The Metals are good conductors of electricity and heat, and are capable of being worked in endless ways. Both they and their Alloys, like Brass, Bronze, etc., exercise a profound influence in modern life. The non-Metals are often gaseous and bad conductors of heat and electricity.

From a chemical point of view the distinction between the two groups can be seen in the oxides which they form with the element Oxygen. The Metals combine to produce basic or alkaline oxides, the non-Metals acid oxides. In the first case we have compounds which neutralise acids, like Soda and Magnesia. In the second we get compounds sour to the taste, and capable of being neutralised by a base like Soda. At the same time we cannot draw any absolute distinction between the two classes. Some elements like Antimony and Arsenic form both acid and basic oxides.

The Elements may also be divided into what are known as electro-positive and electro-negative groups, corresponding to the behaviour of their compounds in Electrolysis, or decomposition by the electric current. For there the metal

appears at the negative pole or electrode and is styled "electro-positive," whilst the other components appear at the positive pole and are called "electro-negative." The position of Hydrogen is curious. It is classed amongst the non-Metals but it is electro-positive in character, and more nearly resembles a metal than any other element with which we are acquainted.

The object of the chemist is to study and find out all about these elementary bodies which we have been looking at, and to discover what is the result of different elements

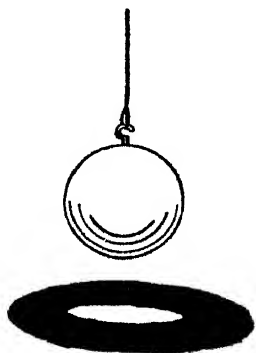


FIG. 4. THE BALL WHEN HEATED REFUSES TO PASS THROUGH CIRCULAR OPENING

or compounds interacting with each other. Then, too, the properties of the various substances formed must also be examined. This is done by subjecting the bodies under examination to physical and chemical change. There are great differences between these two forms of procedure, and there are also relations between them which at first sight are not so apparent.

If we take a piece of Iron and strongly heat it, perhaps to redness, and then allow it to cool down we shall find that it will return once more to its former state. Its properties remain unaltered. If we carefully measure the bar when hot we shall notice an increase in its length. When cold once more that increase is lost. The change is not permanent. So also, if we take a metal ball (Fig. 4) which when cold will pass easily through a circular opening, and heat it strongly, we shall find that it will no longer do so. On cooling, however, it resumes its former size.

Here, again, the change is not permanent. If the piece of Iron were melted down to a liquid and allowed to cool, the resultant mass would still be Iron. It would have suffered no permanent change or transformation. Its composition would remain unaltered. Let us take it once more and after coiling

a length of insulated wire round it, let us join up the ends to an electric battery (Fig. 5). On passing the current we shall find that our piece of Iron has now become a magnet and is capable of attracting iron filings. But when the current is cut off these filings at once drop down. The Iron has lost its magnetic properties. It does not permanently retain them. If, however, the Iron be exposed to the action of air and moisture for some time, it will gradually suffer a change and become coated with a deposit of rust. It has combined by chemical affinity with the Oxygen of the air to form an Oxide, a compound with new properties. The Iron has partly disappeared and its place has been taken by a new substance. This is chemical change and it has permanently

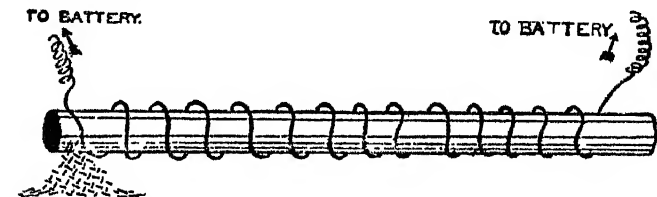


FIG. 5. IRON BAR RENDERED MAGNETIC BY ELECTRIC CURRENTS AND CAPABLE OF ATTRACTING IRON FILINGS

affected the Iron. The other forms of change are physical and have no enduring qualities.

The number of compounds which the chemist is able to produce from the Elements and their various combinations is very great. An endless series of transformations of Matter spreads ever out before us. By Natural processes often hidden from our eyes, on the surface of the earth, in the dark hidden depths below, in our very bodies themselves, under the waters of oceans and seas, in laboratories and factories, Matter is being changed and transformed into countless substances, compounds, often very complex in character, and the transformations effected are definite, for this is the very essence of chemical change. The elements combine only in certain proportions fixed by certain laws and there are no intermediate products. The rust on our piece of Iron is one specific form of combination. We may

have other Oxides, it is true, the result of a combination with Oxygen in some other proportion by weight, but the same principle holds good.

The various forms of Energy such as Light, Heat, Electricity, etc., are all capable of effecting chemical change in bodies, and thus it is that the chemist often employs purely physical processes in his investigations of the properties of Matter. When Light falls upon a body part of the Energy by absorption is transformed into Heat. The body becomes warm, and often chemical action takes place under the influence of such radiation. A mixture of Chlorine gas and Hydrogen will unite and combine in sunlight with an explosion to form Hydrochloric Acid. Heat, too, produces chemical change. A little red Oxide of Mercury heated in a test-tube will give us Oxygen and Mercury, two substances with entirely fresh properties. Electricity, too, is capable of splitting up water into its constituent gases, Oxygen and Hydrogen, and the chemist is always open to make use of any of these agents if it suits his purpose to do so.

Physical and chemical changes are related to one another. Our very bodies tell us this. The Oxygen of the air in respiration circulates through the lungs, aerating the blood, and, combining with the Carbon, produces heat by oxidation. This and the consumption of food help to keep up the temperature of the body and replenish its stores of energy. The fire in our grate, radiating out its pleasant warmth into the room beyond, is another instance. Heat diffuses through our bodies, but all the time chemical change is taking place in the grate. Gases and volatile products, the result of decomposition, pass rapidly away, leaving mere ashes and cinders behind. The coal has disappeared. But in doing so it has produced a physical change in our bodies, and, moreover, has been transformed into new substances with new properties.

The Symbols or distinctive letters attached to each of the Elements are not only representations of their names in an abbreviated form, but they also have a quantitative

signification as well. Thus Cl is one atom of Chlorine and its weight, if Hydrogen be taken as unity (approximately), is 35.46. C is one atom of Carbon, and its atomic weight is 12. A reference to the table of Elements will make this clear. A collection of atoms forms a molecule. Thus a molecule of water is one in which one atom of Oxygen is combined with two atoms of Hydrogen. One molecule of Ammonium Chloride (Sal-ammoniac) consists of one atom of Nitrogen, four of Hydrogen and one of Chlorine. And these molecules represent the smallest part of any of these substances, water or Sal-ammoniac, which can take part in or result from any chemical change.

So far we have been dealing with single molecules. A numeral before them increases their number. Thus we can have two molecules of Hydrochloric Acid added to one of Zinc, and as a result we shall get one molecule of Zinc Chloride and one molecule of Hydrogen. Moreover, the sum of the atomic weights on both sides will be equal.

If a formula contains only two Symbols, the name of the compound generally ends in ide. Thus we have Lead Sulphide or Sodium Chloride. Sometimes a Symbol is repeated in a compound and the prefix tells us the number of times this occurs.

Thus we have :—

Mon=Once (*monos*, single, Grk.) : Carbon-mon-oxide.

Di=Twice (*duo*, two, Grk.) : Carbon-di-sulphide.

Tri=Three (*tria*, three, Grk.) : Phosphorus-tri-chloride.

Tetra=Four (*tettara*, four, Grk.) : Carbon-tetra-chloride.

Pent=Five (*pente*, five, Grk.) : Phosphorus-pent-oxide.

If we have two compounds consisting of the same Elements, and if one contains more Oxygen or Phosphorus, etc., than the other, the compound which has the larger proportion of the Oxygen, etc., ends in ic and the other in ous.

Thus :—

Nitrous Oxide=one atom of Oxygen.

Nitric Oxide=two atoms of Oxygen.

Phosphorous Acid=three atoms of Oxygen.

Phosphoric Acid=four atoms of Oxygen.

Ferrous Sulphate=four atoms of Oxygen.

Ferric Sulphate=twelve atoms of Oxygen.

Sometimes in a series of compounds the proportion of Oxygen is indicated by the prefix *per* (*per*, thoroughly, Latin). Thus: Iron per-oxide when the proportion of Oxygen is higher than in the lower Oxide—Ferrous Oxide.

Sometimes the prefix *hypo* (*hypo*, under, Grk.) is used to denote a compound having a lower proportion of Oxygen than another. Hypo-chlorous Acid has less Oxygen than Chlorous Acid.

The names of Salts depend upon the Acids from which they are derived. Acids ending in *ic* have Salts in *ate*. From Nitric Acid we get Nitrate of Potassium. Acids ending *ous*, however, give us Salts in *ite*. Nitrous Acid give us Nitrite of Potassium.

CHAPTER IV

CHEMICAL COMBINATION. HOW THE ELEMENTS COMBINE WITH ONE ANOTHER

CHEMISTRY is not so much concerned with the investigation and consideration of substances which suffer no material change as it is with those bodies whose composition is affected by means employed to that end. New substances, too, which are the result of the chemist's labours, are especially objects of examination.

The chemist takes Elements and by various means at his disposal causes them to combine together to form fresh compounds. He studies the properties of these compounds which are the result of the chemical change to which they have been subjected. Compounds also are taken and caused to react with other Elements or Compounds to produce again fresh substances. At the same time the chemist finds that his operations are governed by certain Laws, definite and well defined, so that his work is by no means haphazard or irregular. This is seen in Chemical Combination as well as elsewhere. Some of these Laws are common both to Chemical and Physical operations. They govern the changes which take place when those little particles of Matter—the Atoms and Molecules—are combined together (*vide* Chap. v).

And here it is necessary to form clear ideas as to what we mean by bodies compounded or made up of various Elements—Chemical Compounds as they are called. Otherwise we might be misled into regarding them as mere Mixtures.

Suppose that some fine filings of Iron are mixed together with an equal weight of powdered Sulphur or Charcoal.

It would be possible to separate the one from the other without the necessity of any chemical operation. On carefully looking at such a mixture with a lens, or even with the naked eye, it would appear to be full of little dots of yellow and black; and a magnet held close above the mixture would abstract and bring out all the Iron filings, and only the Sulphur and Carbon would remain. The individual properties, too, of the components of the mixture remain unaltered. Again, a mixture of sand and sugar can be made in any proportions we like, forming a dull grey powder. If a small portion be placed upon the tongue, the sweetness of the one and the grittiness of the other will tell us that they are mechanically mixed, the one with the other. We can grind them up as much as we like, reduce them to the finest of powders, but the individual particles still retain their own characteristics. With chemical compounds it is otherwise.

Much may be learnt of various substances by causing them to combine through chemical action. The results are known as Compounds, and they differ entirely from mere mechanical Mixtures. They all possess a definite composition, and are always united in definite proportions.

Suppose that some Iron and Sulphur be heated together very strongly; very soon the mass becomes red hot, and after cooling down it may be examined. A dark compound is the result: it is Iron Sulphide; the two Elements have combined together to form a Compound utterly unlike the original constituents. They have disappeared altogether, vanished into a substance with fresh characteristics. Their identity is lost. The composition of the new substance will always prove to be the same. It will be found to contain seven parts by weight of Iron to four parts of Sulphur. A variation in the weights of the original Elements will but give us the same results. If equal weights be taken, some of the Sulphur will be left over. It would combine with the Oxygen of the air and pass away as a gas with an unpleasant smell. If an excess of Iron be taken, some of it would remain as an Oxide.

Take the case of ordinary Water. This is a distinct chemical Compound formed by the union of Hydrogen and Oxygen in the proportion of one part of the latter to two parts of the former. And always its composition remains invariable.

We may therefore say that in Chemical Combination the Elements always unite in fixed and definite proportions. And this is a fundamental Law in Chemistry. Its definition is complete. The weight of the Sulphide mentioned above is equal to the sum of the weights of the original Elements.

Such an experiment where eleven parts of a Compound are formed from seven of Iron and four of Sulphur, and in the case of water nine parts by weight from eight of Oxygen and one of Hydrogen lead us on to further considerations.

These equivalent weights, as they are called, of all Elements can be expressed in terms of one common standard, and it is usual to take Hydrogen as unity 1. Thus the equivalent weights of Oxygen, Iron, Sulphur, Nitrogen, etc. are 8, 28, 16, 7, etc.

Now, many of the Elements have more than one weight since the same Elements give rise often to more than one product. Oxygen and Nitrogen form five different compounds, while Copper combines with Oxygen to form two distinct compounds—Cuprous and Cupric Oxides. In the former eight parts by weight of Oxygen are united to sixty-three of Copper, and in the latter to 31.5 parts. Thus we have two equivalents in the case of Copper, 63 and 31.5; and these numbers are simple multiples of one another. They illustrate the Law of Multiple Proportions. If two Elements form compounds with each other, the masses of one that combine with a fixed mass of the other bear a simple ratio to one another.

Take the case of Nitrogen with its five different compounds of Oxygen. In the first, 14 parts of Nitrogen Gas are combined with 8 parts of Oxygen; in the second with 16 of Oxygen; in the third with 24 of Oxygen; in the fourth with 32; and in the fifth with 40 of Oxygen. In other words, the figures bear a simple relation to one another of 1, 2, 3, 4, 5.

Chemical Combination

When bodies combine together to form fresh substances, they do so under varying conditions. The change may take place in a moment as when Oxygen combines with Hydrogen to form water. Unless precautions are taken to avoid it, an explosion announces the fact. On the other hand it is possible to cause two gases to combine together in the quietest way possible. Thus Ammonia Gas and Hydrochloric Acid will combine without any inconvenience to form a dense white cloud of Ammonium Chloride (Salt-Ammoniac). Thus we get from two colourless gases a solid body by Chemical Combination. At the same time heat is evolved (Fig. 6).

If a piece of Sulphur be burned in a jar of Oxygen Gas, it will form Sulphur Dioxide, a compound of Sulphur and Oxygen. A beautiful blue light is seen at the time, but there is no explosion. The action, however, is soon over. On the other hand, if a piece of clean Iron be exposed to the air outdoors it becomes "rusty," and from its surface little scales of a compound of Iron and Oxygen may be scraped. But the action takes some days or even weeks to accomplish.

One of the signs of Chemical Combination is the evolution of heat. Indeed, this is one of its chief characteristics. We have seen above that a mixture of Iron and Sulphur if heated begins to glow strongly under the influence of the chemical action to which it is subjected. Much heat is evolved. It was heat which caused the combination to begin and helped the chemical action. Then the whole mass spontaneously becomes red-hot, and it is some little time before the action quietens down. Again, if a piece of Phosphorus be placed in a jar of Oxygen (Fig. 7), the action is sometimes so unrestrained that the Phosphorus will take fire spontaneously in its eagerness to combine with the Oxygen. When this happens, both heat and light are evolved.

Not all examples of combination, however, produce such results. The heat, for instance, emitted by a bar of Iron as it slowly rusts away is very little, by comparison, though

there can be no doubt that it is emitted. On the other hand, if Iron, in a minute state of division be shaken into the air, it will often become red-hot.

If it be true, then, that heat is produced by Chemical Combination, such heat must possess Chemical Energy. And this can be transformed in various ways, for instance, into Motion. Thus we get our steam-engine working through the burning of Coal. All plant life, too, is an example of this fact. In building up its cells and tissues, the plant obtains Energy from the heat of the Sun, and the total amount is

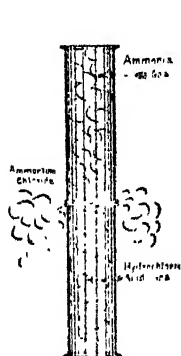


FIG. 6. AMMONIUM CHLORIDE FORMED BY HYDROCHLORIC AND AMMONIA GASES

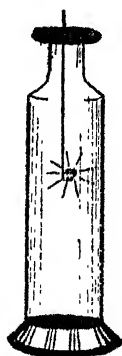


FIG. 7. BURNING PHOSPHORUS IN A JAR OF OXYGEN

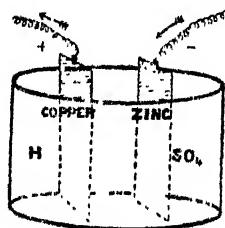


FIG. 8. DECOMPOSITION ILLUSTRATED BY THE ACTION OF A SIMPLE ELECTRIC CELL

unchangeable. Transformations take place in many different ways, but they are all subject to the great Law of Conservation of Energy. There may be many different forms of Energy, but they are all converted one into the other without loss. So, too, in the transformations of Matter, the chemist knows that in such cases, there is neither gain nor loss of any of the material which he uses. The Mass remains constant.

An interesting result of Chemical Combination is seen in the formation of new substances, with new properties, and that, too, under unlikely conditions sometimes. The combination of Oxygen and Hydrogen, two colourless gases,

to form with an explosion little drops of water, one of the commonest substances in the world, is sufficiently astonishing to the person who has never witnessed the experiment. To the savage in the primeval forest it would be put down to the workings of an evil spirit.

The myriad forms in which Combination occurs, thus furnishing us with substances of every degree of complexity, the study of their properties, and the reactions to which they may be subjected, all this and far more it is the business of the chemist to investigate. The process never ends; new bodies with entirely new properties are the products of our laboratories to-day; it will be the same as the years go on. The gain to the human race will be very great.

And yet if we consider the Elements which unite to form those innumerable compounds to which we have alluded, we cannot help being struck by the fact how very few there are, comparatively, which enter into the composition of those bodies. By far the greater number of ordinary compounds with which we are acquainted are combinations of Carbon with such elements as Oxygen, Hydrogen and Nitrogen. Of them all, the element Carbon enters into combination with the greatest number of substances. Indeed, without it there would be an end altogether to Organic Chemistry—the study of the Carbon compounds.

If Combination consists of those reactions between various elements which we have outlined above, Decomposition is the reverse of this. Bodies are split up into their original constituents or into fresh substances. Thus in a simple electric battery consisting of Zinc and Copper plates standing in Sulphuric Acid (Fig. 8), the liquid is decomposed into Hydrogen which is given off at the Copper plate and molecules of Sulphur and Oxygen which with the Zinc form Zinc Sulphate. Thus a double decomposition of liquid and metal takes place with the formation of an electric current. If some chalk be dissolved in vinegar it will gradually decompose and finally disappear. A gas called Carbon Dioxide will be given off with entirely different properties. Salt and Sulphuric Acid will give us a pungent, acrid gas called

Chlorine, and a solid known as Sodium Sulphate. Both are very different from the original substance.

In chemical combination heat is often evolved. So, too, in decomposition, and sometimes spontaneously. Thus quicklime if it be exposed to the influence of air and damp will quickly attract all the moisture possible, fall to pieces of its own accord with evolution of heat, and be decomposed into what is called Slaked Lime. Sometimes we can replace one Element by another, make them change places in fact, as the result of Decomposition. If we pass water in the form of steam over Carbon heated to a very high temperature, the water will give up its Hydrogen, and the Carbon will take its place.

The result is Carbon-mon-Oxide and Hydrogen. We mentioned above that water can be decomposed. When this takes place it is found that one volume of Oxygen appears with two volumes of Hydrogen. These are known as the Combining Volumes, and they always bear to each other in every case the same simple relation. Thus in the Oxides of Nitrogen already mentioned, in the first we have two volumes of Nitrogen united to one volume of Oxygen, while in the third we have two volumes of Nitrogen to three volumes of Oxygen, and so on.

In the case of Hydrochloric Acid, a combination of Hydrogen and Chlorine, we have one volume of Hydrogen united to one volume of the latter gas. In Ammonia Gas, one volume of Nitrogen is united to three volumes of Hydrogen.

As in the Chemical Combination by weight, so too we find in the combining volumes of gases that they are just as definite and fixed.

It is now necessary to consider another feature of Combination. We have seen that different elements combine with one another to form various compounds with characteristic properties of their own. It has been found that the atoms of the Elements when combining unite with one another with different powers.

Take, for instance, the compounds of Chlorine, Oxygen,

Nitrogen and Carbon with the element Hydrogen as expressed below :—

In the first compound, Hydrochloric Acid, one atom of Chlorine unites with *one* atom of Hydrogen to form one molecule of the gas. In the second compound, Water, one atom of Oxygen unites with *two* atoms of Hydrogen to form one molecule. In the third, one atom of Nitrogen combines with *three* atoms of Hydrogen to form one molecule of Ammonia Gas. And in the fourth compound, Marsh Gas, one atom of Carbon unites with *four* atoms of Hydrogen to form one molecule of gas.

From this we see that the atoms of Chlorine, Oxygen, Nitrogen and Carbon possess different powers of uniting with or holding in Chemical Combination the element Hydrogen.

We say, then, that in the first compound, the Chlorine atom can only bind one atom of Hydrogen to itself. It is, as we say, Univalent (Lat. *unus*, one: *valere*, to have power). In the second compound the Oxygen atom can bind two atoms. It is di-valent (Lat. *duo*, two: *valere*). In the third case the Nitrogen atom has three times the power of uniting. It is tri-valent (Lat. *tres*, *tria*: *valere*). And in the fourth compound the Carbon atom has four times the power. It is quadri-valent (Lat. *quattuor*: *valere*). There are, however, atoms which have greater powers than these, but we must consider them in terms of another element save Hydrogen, for no element combines with more than four atoms of that gas. We must take Oxygen, since most elements combine with it. We find that there are elements which hold five or more atoms in combination.

But there is a limit to the binding powers of atoms. Seven (or possibly eight) is the highest. Hydrogen (and Chlorine) one. For the most part Hydrogen is taken as Unity. Some atoms possess more than one power—Carbon which is quadri-valent is sometimes bi-valent (power of two), as in Carbon-bi-sulphide. One atom holds two of Sulphur in combination. So, too, in the atoms of Iron and Sulphur.

The rare gases Argon, Neon, etc. possess no powers of uniting with other elements. They are dull, sluggish, inert.

There is, therefore, not the same exactness with regard to the binding powers of atoms in combination as we saw in the case of combining weights and volumes. The measure of the power of atoms to unite with other atoms is not fixed and definite. The very temperature, for instance, causes a variation. But the principles enunciated are useful in their way. They help us to classify the atoms of elements though we cannot say what intrinsic property gives them their individuality .

Sometimes the chemist wishes to find out the composition of some compound which has resulted from the combination of various elements together. This he does by Chemical Analysis

Without going into unnecessary details, a mention may be made of the way in which such a process may be conducted.

A body may be dissolved in water to form a solution and then subjected to chemical reaction by means of the addition of acids, gases or other means. In other words, the body is subjected to chemical change which causes, perhaps, a precipitate to fall which can be collected and examined. Not all bodies behave in the same way. Certain bodies are insoluble in water and some acids. Others are soluble, and thus we can subject the solution to other agents such as gases, etc., which cause chemical changes to come about. In all such cases we obtain reactions or results of changes induced by various processes. The effect in each case is carefully observed, and by these means the chemist is able to classify and arrange various substances in relation to the tests to which they have been subjected. Thus it is possible to discover whether a body contains Iron or Gold or Arsenic or any other element.

When this question is settled the chemist will try and find out whether the Iron or other element is combined in the form of a Chloride, or Nitrate or Oxide, or in any other form. In each and every case it is possible to determine accurately the composition of the original substance. And in conduct-

ing such an Analysis, we may arrive at two different conclusions.

We can simply determine what substances are present in the original body without determining the relative quantities present—or we may also say in what proportions they are present. The first method would be a Qualitative Analysis, the second method is a Quantitative one.

Suppose that we have a small quantity of a white powder and we want to find out what it is—to make a Qualitative Analysis of it—we might proceed as follows :—

Some of the substance is heated. It does not melt, but crackles slightly. We now see if it is soluble in water. It is soluble. Hydrochloric Acid causes no change. Sulphuretted Hydrogen gives no precipitate. Sulphuric Acid causes a gas to be given off from a portion of the solid substance which fumes in the air. This looks as if the substance was Chloride of Sodium, since the reaction is a familiar one. To make sure that it is a Chloride, we add to some of the original solution a little Silver Nitrate in solution. A dense white precipitate of Silver Chloride occurs. The substance is a Chloride, and probably that of Sodium. It might, however, be the Chloride of Potassium. To make sure we take a platinum wire and, dipping it in the solution of the substance, hold it in the colourless flame of a Bunsen-burner. The flame is coloured an intense yellow—Sodium is present. Examined with a spectroscope we should find that the Spectrum is crossed with a bright yellow line. It is the well-known Spectrum of the metal Sodium. Potassium would have coloured the flame purple and the Spectrum would reveal two bright lines, one at the extreme red and the other at the extreme violet. The substance is evidently Sodium Chloride or common salt.

Again, suppose that we want to find out how much Sodium is present in 60 grams of the salt which we have analysed.

Salt is composed of Sodium and Chlorine, of which the atomic weights are 23 and 35.5 (approximately).

Hence 58.5 grams of Sodium Chloride give us 23 grams of Sodium, and 60 grams will give us 23.5 grams.

CHAPTER V

ATOMS AND MOLECULES: THE WORLD OF THE INFINITELY LITTLE

THE researches which have been made of late years into the constitution of Matter and the startling results which have been promulgated—results which require many of our old ideas to be modified—make it necessary to look a little closely into the question of Atoms and Molecules. An acquaintance with them from the chemical point of view will pave the way to a more intelligent appreciation of the labours and results of those Physicists who have done so much to unravel the mysteries of Matter.

We saw in the last chapter that when different elements unite together to form compounds, they do so in fixed proportions, and each of them possesses a fixed combining weight. This is known as the Law of Definite Proportions. It tells us that the composition of a chemical compound is definite and constant. And it lies at the very root of the principles of quantitative analysis. From the uniformity of the composition, say, of Silver Chloride, we can determine the amount and percentage of Silver present in a shilling or sixpence by precipitating the Silver in it as a Chloride and weighing it. The amount of the metal present in the coin can then be deduced. But we could not do this with any degree of accuracy if we did not know that the composition of Silver Chloride consists of 35.46 parts of Chlorine combined with or united to 108 parts of Silver. And in those cases in which by combining various elements together we get not only one compound but in some cases two or more products, we find that our operations are governed by another important Law, that of Multiple Proportions. These

Laws have been subjected to much examination and experiment and their truth is abundantly confirmed.

John Dalton, of Manchester, was the first to enunciate the Laws we have mentioned, and he based on them his Atomic Theory of Matter. This was based on the old Greek conception that it was possible to divide up Matter to such an extent that finally there only remained its ultimate particles. By a system of division and subdivision we can imagine it to be split up and resolved into infinitesimal particles, until at last the limit of resolution would be reached. This was the theory held by the Greeks, and Epicurus, the Attic philosopher, held the view, for which he was arraigned, that the world was composed of material atoms. Lucretius, another philosopher and poet, who was a warm supporter of the tenets held by Epicurus and his followers, developed in his "De Rerum Natura" a theory on the nature of the world. He believed that it was an absolute void and composed of minute atoms. These indivisible atoms (*atomos*, indivisible, Grk.) were supposed to be invisible and to be infinite in number. They could not be destroyed and, moreover, possessed certain shape and weight. The Greeks imagined them always to be falling through space and rebounding against each other.

Dalton revived the ancient theory of the subdivision of Matter, and taught that all the little particles in an element are exactly alike in size and weight, etc., and that they are imperishable and unchangeable. Of them the whole universe was constructed. Every chemical operation such as the combining of elements together to form compounds, etc., postulated their existence. Their number, however, was finite. One could divide up Matter to a certain point and then a limit was reached. Matter possessed a structure which was "grained" or "discrete," and "small shot" was the resemblance attributed to the little particles of gases. These would fill the whole of a containing vessel. Dalton's theory was of enormous importance in establishing the definite character of chemical combination. According to the theory atoms of a certain weight combine

with others of a certain weight in definite proportions, and all fractional parts are inadmissible. Thus combination cannot take place in any uncertain and haphazard way, but only in obedience to the Laws of Definite and Multiple Proportions.

Now, since the ultimate particles of a substance like Hydrochloric Acid consisting of the elements Hydrogen and Chlorine might be further decomposed into these constituent bodies, the smallest particle of such a compound capable of existing is termed a Molecule. It is made up of Hydrogen and Chlorine atoms. Look at a familiar substance like water. The smallest particle consists of two atoms of Hydrogen united to one of Oxygen. The molecule thus consists of three atoms. Other substances contain more. Thus Ammonia contains four atoms, and Sulphuric Acid seven atoms. Some organic compounds contain a great many more. Glycerine, for instance, contains fourteen atoms, and Cane Sugar no less than forty-five.

That curious modification of Oxygen called Ozone contains an extra atom, which is always liable to fly off. In doing so it displays very active powers. These single atoms which we do not find existing often by themselves are spoken of as being in the Nascent State (*nascor*, am born, Lat.). In the case of Ozone, the liberated atom possesses strong oxidizing powers. Chlorine is a gas which has the property of bleaching cloth, paper, etc., but only in the presence of water. It then combines with the Hydrogen and sets free the Oxygen which at the moment of its liberation from molecular bondage acts upon the colouring matter present in the cloth or paper and destroys it.

In a preceding chapter (Chap. II.) we have seen that all bodies, solids, liquids and gases consist of incredible numbers of minute little particles—the molecules—which are in a constant state of motion. Tightly packed in a solid, less strongly held in liquids, and possessing the greatest freedom of movement in gases, they are ever colliding against and rebounding from one another. And although they are so minute that their diameter is five thousand times smaller

than the most minute object visible in the microscope, yet the so-called "Brownian Movement" revealed their presence in liquids many years ago (Chap. II).

The invention of the Ultra-microscope has enabled investigators to examine these movements with a greater degree of accuracy. It was shown by Ehrenhaft that this phenomenon of particles dancing about as it were in all directions was not confined exclusively to liquids. He caused a strong charge of electricity to pass between silver poles and thus produce in the surrounding air a dust of exceedingly fine metallic particles. Their movements corresponded to those observed in liquids, but they exhibited a greater freedom. Later on Perrin, in some very ingenious experiments by means of an emulsion of gamboge in water, conclusively established the objective reality of these tiny particles. And indirectly he proved the truth of the Kinetic Theory of Matter (*kineō*, move, Grk.). The Molecules are always in motion. If a body be raised to a white heat, it has been calculated that the molecules will vibrate with a rapidity of the order of six hundred million million times per second. The size of Molecules is infinitely small. And fifteen thousand million million million of them would only weigh (so it is supposed) about a grain.

We must conceive every heated body to be the seat of very energetic molecular vibration. And if this be so we can see how it is that heat produces expansion. Increase of the vibration of the little particles drives them further and further apart from each other and so the body expands. And this we observe also in the case of liquids and gases. In this latter state of Matter, the little molecules fly about like little balls with enormous speed in every direction. In the case of Hydrogen Gas, the number of collisions in terms of millions per second has been calculated to be about 7600.

The little particles which Dalton conceived to be the ultimate units of Matter and to which he gave the name of Atoms (*α*, not ; *temnō*, cut, Grk.) suggested to him that their relative weights must be considered in terms of their combining weights. In that case, if Hydrogen be taken as

unity, Dalton suggested that the Atomic weight of Oxygen, for instance, was 8, the molecule of water containing an atom each of Hydrogen and Oxygen. But he was not quite right in some of his conclusions. For he could not say with any degree of certainty how many atoms there were in any chemical compound, but assumed that atoms of the one element were all joined up to atoms of the other element, as, for instance, in water. In this case the ratio of the combining weights is 8 to 1 (Oxygen and Hydrogen). Seeing that the molecules of gases are ever in motion and the fact that they are capable of expansion and contraction, Gay-Lussac endeavoured to place the Atomic Theory of Dalton upon a firmer foundation. For in spite of all that he had done and the rules which he had laid down, he felt that his theory was not correct.

Does a molecule of water contain only one atom of each of its constituent elements? Gay-Lussac showed that the volume of a gas varies with the temperature. If, for instance, the temperature be raised 1°C . the volume is increased by $\frac{1}{273}$ part of that occupied by it at 0°C . Now, Boyle had previously found that the volume of a gas varies also according to the pressure applied to it. If we double the pressure, we decrease the volume one-half, or if we halve the pressure, the volume is doubled. Thus we see that the volume of a gas is inversely proportional to the pressure. If we increase the pressure, say, four times, the volume is immediately reduced to one-fourth. In all cases there are certain corrections to be made for temperature, atmospheric pressure, etc. In the second of these factors, since the barometric pressure is continually varying, the volume of a gas under examination must be corrected in terms of the variation. So, too, in the case of water, vapour, etc. All must be taken into account in order to obtain a correct reading of the volume.

From what has been said about the expansion and contraction of gases, it is evident that if the temperature of a gas be reduced to -273°C . the volume would be reduced to zero. No further diminution would be observed. For

if the volume be cooled to -1°C . it will be decreased by $\frac{1}{273}$, the pressure remaining constant all the time. Then if it be cooled to -2°C . the volume will be reduced by $\frac{2}{273}$ and so on, the pressure still remaining constant. Thus at a temperature of -273°C . the volume would be reduced to zero and the temperature, -273°C ., would be the Absolute Zero.

We can hardly imagine the thermometer sinking to such icy depths. Even Science with all its triumphs has not achieved this result. The boiling-point of Helium is the nearest approach, -268°C . It is probable that all molecular activity would cease at such a temperature, that the restless movements of all those myriad particles in solids, liquids and gases, would come to an end, that Matter would be at rest.

The experiments of Gay-Lussac led him to enunciate a Law of Volumes which further elucidated the theory of Atomic weights. This law states that "the weights of equal volumes of gases are proportional to their combining weights or to simple multiples of these." From this we can deduce the atomic weight, for instance, of Oxygen. The combining weights of Oxygen and Hydrogen are 8 to 1, and since one volume of Oxygen combines with two volumes of Hydrogen, the atomic weight of Oxygen must be 16. Moreover, there is always the same definite character in the combination of gases by volume as by weight. The ratios are always expressed by simple numbers.

When Hydrogen and Chlorine combine together we get as the result of the combination of one volume of each a product—Hydrochloric Acid—which is composed of two volumes. In the case of water, two volumes of Hydrogen combining with one volume of Oxygen give us two volumes of water in the form of vapour under the action of the electric spark. There is a contraction of volume from three volumes to two. If we take a gas like Ammonia we find that the proportion in which the two constituent gases combine is as 1 to 3. But contraction takes place so that the Ammonia produced only occupies one-half the volume occupied by the mixture of the two gases. The

same numerical simplicity, however, is observed, such as 1:1, 1:2, 1:3, and so on. There is always a simple relation of the volumes to one another and to the final volume observed.

The relations between gaseous volumes and their products led Avogadro, the famous Italian physicist, to suggest that "equal volumes of all gases must contain the same number of molecules at the same temperature and pressure." This Law is universally accepted to-day, and it leads to interesting conclusions.

Fresh light is thrown on the molecular structure of some of the gases such as Oxygen, Hydrogen, Chlorine and others. In the case where two volumes of Hydrogen and one volume of Oxygen Gas combine, as we know, to form water, this water, reduced to vapour, occupies two volumes, and therefore the Oxygen molecules must split up into two separate atoms, which therefore are divided up between the molecules of steam, which are double those of the Oxygen ones. Thus we say that the Oxygen molecule is really made up of two atoms. It is, in other words, twice as heavy as the atom. So also in the case of Hydrogen and Chlorine. The Atomic Theory of Dalton in the light of the hypothesis of Avogadro has been generally accepted and applied to all questions of chemical phenomena.

In determining the atomic weights of the elements it is necessary to take one as a standard of comparison and to express all the others in terms of it. Without going into the question to any extent, it is interesting to observe that these weights are generally arrived at by experimental comparison with the element Oxygen, sometimes directly and sometimes in an indirect way. In the case of such an element as Carbon the direct method can be employed, and if the atomic weight of oxygen be taken as 16, which is the recognised value to-day, that of Carbon works out at 12, since 32 parts by weight of Oxygen combine with 12 parts by weight of this substance. But it is not so easy to determine some of the others. But in the interests of Chemical Science it is necessary that the relative weights

of the atoms of all the known elements should be ascertained with the utmost possible accuracy. From time to time an International Committee checks the results obtained, as fresh estimates come in. These weights when passed constitute the absolute values until fresh revision takes place.

An accurate estimation of the atomic weight of Oxygen is necessary in all these determinations, and of late years this has been critically examined, and with a degree of precision and accuracy far greater than ever before. It was necessary first of all to prepare Hydrogen of extreme purity, which was successfully accomplished. Then Oxygen of a like purity. The two gases were weighed, combined by means of the electric spark, and the water produced weighed. Its weight divided by that of the Hydrogen gave the atomic weight of Oxygen (Morley). The actual value works out at 15.88, not quite 16. But in order to avoid complication and confusion it is sufficient to call it 16. In this case the atomic weight of Hydrogen is 1.008.

In conclusion we see that Matter is made up of infinitesimal particles called Atoms and Molecules, and it is these which decide the properties of any particular substance. And the electrons in the atoms composing molecules together with their number and arrangement within the molecular structure finally determine the properties of the molecules themselves.

With regard to the atom itself, in the light of modern research we must admit that the old conception of the Dalton atom as an unchangeable unit representing the final limit of the resolution of Matter, has been dispelled by the fresh light shed upon the question by the phenomena of Radioactivity. The history of those tiny entities, the electrons, the smallest conceivable in Science, has taught us that the atom is not the unit of the smallest mass as formerly supposed. The Electron, with a mass nearly two thousand times less than that of the Hydrogen atom, has compelled us to abandon that idea. The atom which modern Science asks us to picture to-day is that of a

miniature solar system—a central nucleus of positive electricity with a system of electrons of negative electricity revolving around it, infinitesimal little planets circling round an infinitesimal sun. The velocity of the electrons circling in their orbit is very great, and the atom therefore must itself contain enormous stores of potential energy. We get some idea of this when we see a body like Radium shooting out at terrific speed Lilliputian particles—projectiles in miniature of positive and negative electricity, protons and electrons, hurled forth as the result of the disruption of the atom

CHAPTER VI

THE AIR WE BREATHE

WE have seen in an earlier chapter (Chap. II) that the ancient Greeks included air amongst the four so-called "Elements" of which the visible world was constituted. Indeed, some of the earlier philosophers and writers considered air to be the First Principle of all things. Many of them, such as Aristotle, Homer, Ctesibius of Alexandria, and Hero, recognised, and made practical applications of some of the more important properties of what we now call atmospheric air, but which they designated by some such terms as Breath, Life, Spirit, etc. Hero actually says that air is composed of myriads of little particles, very light and very minute, and wholly invisible. And this conception comes very near to what we believe to-day, that gases consist of crowds of minute particles ever colliding with, and rebounding from, one another. Air, which is a mixture of different gases, also consists of countless molecules in perpetual motion, and free from all mutual restraint.

Hero, who was a clever mechanician, demonstrated some of the physical properties of air, described the vacuum and a rude form of the modern air-pump. Hesiod, who lived in the age of Homer, and wrote a poem on agriculture, extolled the beneficial effects of air on all living things. Aristotle claimed that air possessed weight. In his physical writings he includes a treatise on the winds.

In these modern days of ours, atmospheric air has been subjected to rigorous physical and chemical tests, and we know far more about its properties than the Ancients ever conceived or thought possible. Moreover, we know that without it all living organisms would perish. The earth

would become as lifeless and as dreary as the moon itself.

Before discussing the air we breathe from a chemical point of view, we must briefly glance at some of its physical characteristics, which are not out of place, we think, in any review of its more important properties.

The extent of the gaseous envelope or atmosphere (*atmos*, air; *sphaira*, a sphere, Grk.) which surrounds our earth has been computed at about forty-five miles in height. It probably exists, however, in a very attenuated or rarefied state through space, but of a density scarcely appreciable

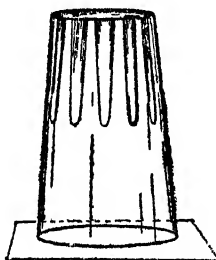


FIG. 9. TUMBLER OF WATER WITH CARD-BOARD SUPPORTED BY ATMOSPHERIC PRESSURE

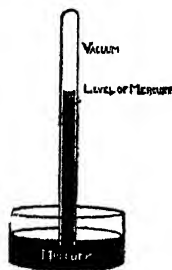


FIG. 10. MERCURY SUPPORTED IN A TUBE BY THE PRESSURE OF THE ATMOSPHERE

by any form of direct measurement. By exploring the atmosphere with kites and balloons carrying self-recording barometers and thermometers, it has been lately found that the atmosphere is divided into two parts, one extending up to a height of about seven miles, and the other lying above it. Its actual weight at the level of the sea is equivalent to about fifteen pounds (14.73) on the square inch. The actual pressure, therefore, upon our bodies is very great indeed, amounting in fact to several tons. We do not feel this enormous weight, since it is equally distributed in all directions.

If we fill a tumbler with water (Fig. 9) and, after placing a slip of stout paper over the mouth, invert the tumbler,

still holding the paper, the pressure of the air will support the paper when the hand is removed. And there are many other ways of demonstrating the same thing. The ordinary Barometer, which consists of a tube of glass about thirty-three inches in length, closed at one end and carefully graduated, serves to measure the weight or pressure also. Its open end is placed downwards in a vessel of Mercury after the tube has been completely filled. The Mercury will sink at once to a height of about thirty inches above the level of that in the vessel, leaving a vacuum at the upper end of the tube (Fig. 10). It is sustained by the varying pressure of the air. When the pressure increases, the column of Mercury rises higher in the tube; when it decreases the level falls. We say that the "glass" is "rising" or "falling," as the case may be.

Since the air is a gaseous body and possesses weight and elasticity, its lower strata or layers on the earth's surface must be more highly compressed than the upper ones. Thus its density varies at different heights above sea-level. This naturally affects the readings of Barometers which for accurate work must be corrected for variations of height, as also for temperature, expansion of the scale, etc. Some instruments (especially of the Aneroid type) are so delicate that they disclose very minute differences in pressure, and may be used to measure different altitudes.

The higher strata of the air are very rarefied, and the physiological effects due to the decrease of pressure become increasingly serious on the human body as the altitude increases. As we ascend higher and higher into the upper atmosphere sickness and increased muscular effort are some of the results, together with difficulty in breathing. At very great heights Oxygen artificially administered has proved beneficial.

Early in the eighth century, Geber, an Alchemist, recorded the fact that many metals when heated became covered with a kind of crust. At the same time their weight increased. A later observer attributed this to a gas which existed in Nitre and was able to sustain flames and re-kindle

a glowing stick. Subsequent investigations proved that all this occurred only when access to the air was possible. Boyle, in 1692, showed that metals absorbed air when strongly heated. But none of the early investigators were able to explain how it was that metals increased in weight when heated. It was Lavoisier, later on, who gave a correct explanation of these phenomena. He placed some Mercury in a flask with a long curved neck, the end protruding into a graduated jar placed in a dish of Mercury (Fig. 11). The

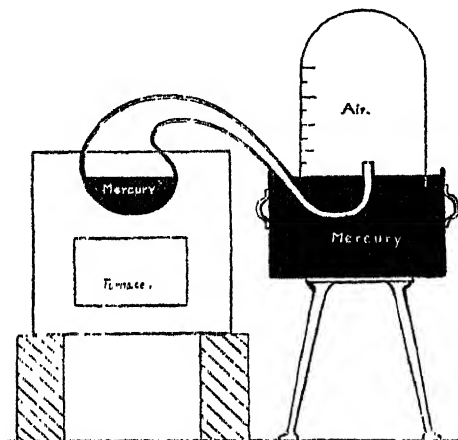


FIG. 11. SEPARATION OF OXYGEN FROM AIR BY MERCURY

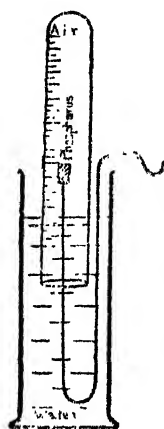


FIG. 12. ANALYSIS OF AIR

height of the metal in this dish was carefully noted and then the Mercury in the flask was heated. After some time it became covered with a black crust, which became red on cooling. At the same time the air in the jar diminished in bulk, but not less than about four-fifths of its original volume. And its properties were altered ; no longer would it support combustion.

The crust when strongly heated in a retort was resolved into shining globules of Mercury and a gas which re-kindled a glowing bit of wood. This gas is called Oxygen.

Thus, when metals were heated, they became covered

The Air we Breathe

with a crust or "calx" of Oxide, as we say, the result of absorbing Oxygen from the air.

But what is the nature of the gas which in Lavoisier's experiment remained in the graduated jar? The Mercury absorbed or combined with the Oxygen and became converted into Mercuric Oxide. What was left? It was Nitrogen, a gas incapable of supporting combustion.

It thus appears that air is composed of Oxygen and Nitrogen in the proportion of about one measure of Oxygen to four measures of Nitrogen. These relative quantities of the two gases remain (with slight variations) invariable in all parts of the world.

We can determine the ratio of the Oxygen to the Nitrogen in the following way :

A graduated tube (Fig. 12) is partly filled with water and inverted in some water in a trough. The level is carefully noted. A small piece of phosphorus attached to the end of a wire is then introduced into the tube and allowed to remain there for some hours. It is then withdrawn and the new level noted. The volume of the original air will be found quite considerably diminished, but about four-fifths will remain. In other words, if one hundred divisions are taken as a standard, twenty-one are absorbed by the phosphorus (Oxygen) and seventy-nine left over (Nitrogen). It is Nitrogen, and may be tested by inverting the mouth of the tube upwards, after closing it with the thumb. A glowing piece of wood introduced will be extinguished. A number of such experiments may be made, but they all give the same result. We shall see, a little later on, what are the properties of these two gases, Oxygen and Nitrogen, the chief constituents of the air. But for the moment we must see whether the two gases are chemically combined with each other or are simply mixed together, in atmospheric air.

Suppose that we mix in a jar four volumes of Nitrogen and one volume of Oxygen, we shall see nothing in the nature of any chemical action. A notable sign would be a rise in temperature, since heat is one of the results of such action.

But in such an experiment as this, we can detect no heat whatever. The mixture appears to be ordinary air; it possesses all its properties.

Again, we saw in Chapter IV that all chemical compounds have a certain definite composition. There are no intermediate substances. A very large number of experiments tell us that the same substances always combine in the same proportions to form the same fixed products. There are three Oxides of Iron, but the relative proportions of Iron and Oxygen present are always the same.

In air, although the relative proportions of the two chief constituents, Oxygen and Nitrogen, are on the whole constant, yet the composition of the atmosphere does vary slightly. A stronger argument is the following: Suppose we dissolve some air in water, for it is slightly soluble, and then boil the water. On analysing the air which is expelled we find that it contains a larger percentage of Oxygen than before, since Oxygen is more soluble in water than Nitrogen. Instead of one volume to four volumes of Nitrogen, the ratio works out at one volume of Oxygen to 1.87 volumes of Nitrogen. How then can these two gases be chemically combined? In that case they would not possess different degrees of solubility.

In modern times a very strong argument has been adduced to support the Mixture theory. By suitable means, air can be reduced to the liquid state. Now, if this liquid is merely a mixture and not a definite compound, we should expect that, if it were allowed to evaporate off, the gas with the lowest boiling-point would boil away more rapidly than the constituents whose boiling-points are higher.

This is exactly what does happen. We know that the boiling-point of Oxygen and Nitrogen (for they have both been liquefied) are respectively 183° and 196° below the freezing-point of water. When liquid air evaporates and boils off, the Nitrogen comes away more readily than the Oxygen, and the remaining liquid is found to be very rich in Oxygen. This is a strong proof that atmospheric air is a mixture of gases and not a chemical compound.

Oxygen is perhaps more widely distributed in Nature than any other element, forming nearly 50 per cent of the crust of the earth, eight-ninths of water and about one-fifth of air, as we have seen.

It can be prepared from the red precipitate (as it is called) which Priestley and Lavoisier made in the old days by heating Mercury in a flask. If a small quantity be placed in a test-tube and strongly heated, the gas comes off. At the same time little shining globules of Mercury collect on the cool sides of the tube. The Compound has been resolved into its Elements.

Mercuric Oxide gives Mercury and Oxygen. Other

Oxides or combinations of metals with Oxygen may be used.

In order to prepare a larger quantity so that it may be collected, we proceed as follows :—

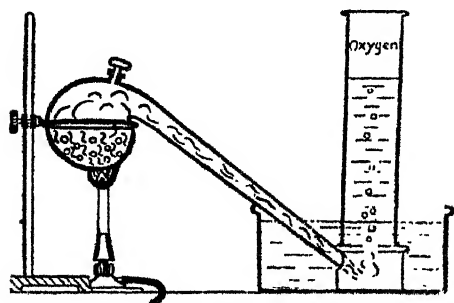


FIG. 13. COLLECTING OXYGEN IN A GLASS CYLINDER BY HEATING POTASSIUM CHLORATE

Some white Potassium Chlorate (a compound of Potassium and Chlorine with Oxygen) is placed in

a retort connected with a piece of glass tube which is bent up at the end and immersed in water. Over it rests an inverted jar filled with water (Fig. 13).

On heating the Chlorate, the Oxygen comes off, and, displacing the water in the jar, may be collected and examined. In laboratory work it is usual to mix with the Chlorate a small quantity of Manganese Dioxide. The gas comes off more readily thereby, and at a lower temperature.

We find Oxygen to be a colourless, invisible gas, slightly heavier than air and sixteen times heavier than Hydrogen. It can be liquefied at a temperature of -181° . It is slightly soluble in water.

Oxygen exhibits great chemical activity even at the

ordinary temperature of the air. We know that Iron if exposed to air and moisture becomes "rusty," combines, in fact, with the Oxygen present, and forms an Oxide. Coal when stored in ships is often liable to spontaneous combustion, especially if there be a lack of ventilation. The absorption of Oxygen is attended by a development of heat through chemical action. If the bunkers are badly ventilated the gases evolved form explosive compounds with the air and thus endanger the ship.

If a little Iron in a minute state of division be shaken into the air, it combines so energetically with the Oxygen that it becomes red-hot. A fragment of Sodium when placed in a jar of the gas at once combines with it, giving out light and heat, and forming an Oxide.

If such phenomena as these take place at the ordinary temperature of the air, we should expect Oxygen to exhibit increased activity at a higher temperature. Let us introduce a piece of Iron wire after heating it very strongly into a jar of the gas. It immediately burns in the most brilliant manner, forming the Oxide. Sulphur and Phosphorus also burn with great brilliancy, forming Sulphur Dioxide and Phosphorus Pentoxide. There is hardly a single element, with the exception of Fluorine, which is not capable of forming Oxides. The rare gases of the atmosphere, Argon, Neon, Xenon and Krypton, are quite inert.

If a few drops of Tincture of Litmus (a blue vegetable dye used to detect acids) be shaken up in a jar in which Phosphorus has been burnt with Oxygen, it at once turns red—chemical combination has taken place, and something has been formed

The Phosphorus has with the Oxygen combined to form the Pentoxide which, dissolving in the Litmus solution, forms Phosphoric Acid

Now, in the old days Lavoisier noticed that certain colouring matters were affected by elements uniting with Oxygen, or, as it had been called up till then, "Empyrean Air" (*en*, in; *pur*, fire, Grk.), and so he called the gas Oxygen (*oxis*, acid; *γενναω*, produce, Grk.). He concluded

that this gas produced Acids, and that they always contained Oxygen, an erroneous idea, as we shall see later on. But the name Oxygen remains to-day.

The phenomena observed when Phosphorus, Sulphur, etc., burn in Oxygen-gas are the result of chemical action and chemical change. And, speaking generally, we say that combustion has taken place, and that Oxygen is a supporter of such combustion. Bodies are said to be combustible which thus unite with it. For the most part heat and light are evolved. Oxygen is not itself inflammable, but under certain conditions (in an atmosphere of Hydrogen, for instance) it will burn. Thus the terms "Supporter of Combustion" and "Combustible" are relative to a certain extent.

Nitrogen, as we have seen, is one of the chief constituents

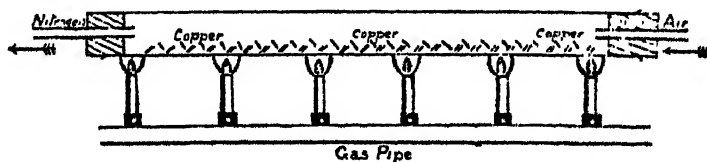


FIG. 14. FORMATION OF NITROGEN BY PASSING AIR OVER HEATED COPPER

of air, of which it constitutes four-fifths by volume. It occurs abundantly in Nature, and plays an important part in animal and vegetable life. Various compounds, such as Nitre, contain it. Hence its name (*nitre*, nitre; *gennao*, produce, Grk.).

In order to prepare Nitrogen, we pass a stream of air through a red-hot combustion tube (Fig. 14) packed full of Copper. The Oxygen of the air combines with the Copper forming the black Oxide and also the red Oxide. The Nitrogen passes out and may be collected. Or we can burn Phosphorus in a jar of air. Phosphoric Anhydride is formed and impure Nitrogen remains

How different Nitrogen is from Oxygen. Although it is colourless, tasteless and inodorous like Oxygen, it is not a supporter of combustion, and at once extinguishes a light

plunged into it. Animals cannot live in it, but its beneficial effects are seen in the air we breathe. Without it oxidation would take place so rapidly that our bodies would burn away as it were in a very short time. Nitrogen moderates and tones down the influence of its too energetic neighbour. It has been liquefied and boils away at 196° below freezing-point of water. It is fourteen times heavier than Hydrogen.

Nitrogen forms five compounds with Oxygen. Nitrous Oxide and Nitric Oxide are the two most important.

Nitrous Oxide is a colourless gas with a sweetish taste, somewhat soluble in water. When inhaled it causes a kind

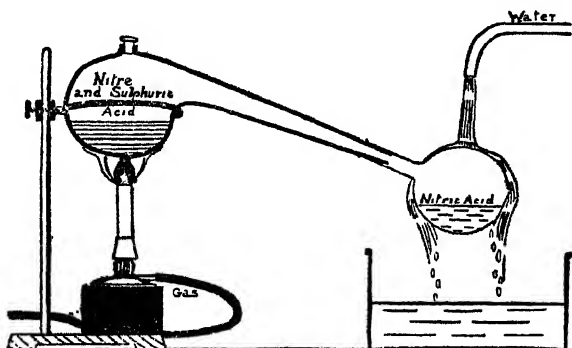


FIG. 15. PREPARATION OF NITRIC ACID IN A FLASK COOLED BY WATER

of intoxication passing into insensibility, and often hysterical laughter. Hence the gas has been called "Laughing Gas." It is used in dentistry. We can prepare it by cautiously heating Ammonium Nitrate.

Ammonium Nitrate gives water and Nitrous Oxide gas. Nitric Oxide is another colourless gas and a feeble supporter of combustion. It combines readily with Oxygen, forming dense red fumes of Nitrogen Peroxide. It is prepared by treating Copper with Nitric Acid.

Nitric Acid is a strong fuming liquid and contains over 76 per cent of Oxygen. This it easily parts with, and so we call it a good oxidizing agent. If we place a piece

of Charcoal into Nitric Acid, after strongly heating it, we can cause it to burn with a bright light.

Nitric Acid may be prepared by carefully heating in a retort (Fig. 15) some Nitre or Saltpetre with Sulphuric Acid. The Nitric Acid distils over and may be collected in a flask cooled by a stream of water.

We must now glance at a very peculiar constituent of atmospheric air, although a minor one. If we stand near an electrical machine in action, or hang up a wet sheet to dry in a cold wind, we become conscious of a peculiar smell reminding us of the seaside. This is due to the presence of Ozone (*ozein*, to smell, Grk.), the result of electrical action upon atmospheric Oxygen. It is really a modification of Oxygen Gas—Oxygen in a condensed state.

A simple means of producing Ozone is by passing a stream

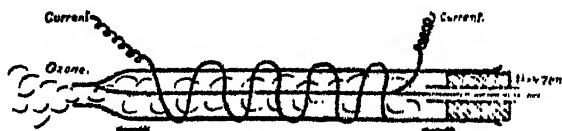


FIG. 16. FORMATION OF OZONE FROM OXYGEN BY AN ELECTRIC CURRENT

of Oxygen through a glass tube (Fig. 16) through which runs a Platinum wire and around which is coiled a similar piece. The Oxygen becomes charged with Ozone when the wires are connected up to an induction coil.

The symbol O_3 of Ozone indicates that its molecule consists of three atoms of Oxygen. The odd atom (compared with Oxygen, which has two atoms) is very unstable and ready to fly off at any time. Hence Ozone is an active oxidizing agent. We call it an allotropic modification of Oxygen (*allos*, other; *trepō*, turn, Grk.), which thus exists in two different forms. Later on we shall come across other similar bodies.

Country air contains more Ozone than that of towns, where its presence can seldom be detected. Its action is greater in spring than at any other time. It gives

that pleasant buoyant feeling to sea air which we all know.

Carbon Dioxide is another important constituent of atmospheric air. It is present only in small quantities (about 4 volumes in 10,000), but its presence can be detected everywhere, in the breath of human beings and animals, in mineral waters and in most cases of combustion. Also in the decay of vegetable and animal matter, and in alcoholic fermentation. It plays an important part in plant life (Chap. xxiii).

The relation between the Carbon Dioxide present in the air and the Oxygen has always been a subject of discussion. There must be some "balance of Nature," as it is called, otherwise animal life, by using up Oxygen and breathing out Carbon Dioxide would gradually pollute the atmosphere, and increase the amount of Carbonic Acid, which is itself a poisonous gas. But here it is that plant life plays so important a part in the general scheme of things. There is always a cycle of operations going on. Carbon Dioxide passes into the air and is decomposed by plants; Oxygen is returned once more and the Carbon is used by the plants to form fresh food for animals. The important point is that the Oxygen content varies but slightly, and that "while the combustion of fuel and vital processes of men and animals result in a local increase of Carbonic Acid and a decrease of Oxygen, vegetable growth causes the reverse, and thus the local variations in the air are equalised" (Benedict).

In towns, of course, and in crowded rooms, the amount of the gas rapidly rises. Much discomfort results, which can only be relieved by adequate ventilation. Expired air contains about 4 per cent more of Carbon Dioxide than air before respiration. The smoky air of towns is full of it. Now, when Carbon burns in a limited supply of Oxygen it forms a very poisonous gas called Carbon-mon-oxide (Carbon+one Atom of Oxygen). This again has a very bad effect on the human body. In crowded rooms it is often present, and especially in coal mines after explosions. From experiments made, it has been found that a very

delicate test lies in the behaviour of canaries towards it. And more so, in fact, than in the case of mice, which have also been employed. With a percentage of gas present amounting to $\cdot 16$, a mouse became giddy and faint at the end of an hour; a canary became much distressed in three minutes. All the experiments and observations made in mines show that canaries are the more susceptible. Further details concerning these gases are given in a later chapter (Chap. vii).

Other minor constituents of the air are Ammonia, the normal amount of which consists of about six parts in one million, and Nitric Acid, the result probably of electrical action and of Ozone. Both play an important part in plant life. From these sources plants obtain the necessary Nitrogen which they cannot directly assimilate in a free state.

There is, however, another side to the question. The presence of acids and impurities of many kinds in the air, saline substances, and so forth, are responsible for the deplorable state into which many of our ancient buildings, like Westminster Abbey, are falling. On all sides we see stonework gradually crumbling and rotting away, endangering the whole structure and fabric of cathedrals, churches, etc., and casting an additional burden upon those responsible for their care and maintenance.

Lastly, there is always present in air a variable quantity of Aqueous Vapour. This humidity depends, however, a good deal upon temperature, and the direction of the wind. Speaking generally we may say that air contains about 60 per cent of the quantity necessary to saturate it. Outside this limit it is either very dry or very moist.

There are minute quantities of certain rare gases in the air which are discussed fully in the next chapter.

CHAPTER VII

CARBON DIOXIDE, CARBON MONOXIDE AND THE RARE GASES OF THE ATMOSPHERE

WE have seen that one of the constituents of the air around us, although a minor one, is the gas called Carbon Dioxide. It is not present in large quantities, but in the proportion of about .04 volumes in every 100 volumes of air. Any excess is harmful and renders the air unfit for breathing. Expired air contains about 4.5 volumes of the gas per cent, and in crowded rooms and halls the percentage may rise to 12 or more volumes per 10,000, rendering the atmosphere very bad by reason of the deleterious effects of the gas on the system. The air becomes foul and the proportion of Oxygen decreases. Headache is the result. Then, too, the waste products of the skin and lungs have also to be considered. Adequate ventilation is therefore imperative, and we find it insisted upon in most modern buildings.

Carbon Dioxide is also produced in large quantities by the burning of fuel of all kinds such as coal and coke. It is given off also by all sorts of decaying Matter, and fermenting material, vegetable and animal. The products of our gardens, fruit and refuse decaying on the ground, are all sources of this gas. In the bottom of old wells there is often a quantity of the gas mixed with the air in dangerous proportions, and adequate measures must be taken before descending into such places. After explosions in mines a quantity of the gas is often left and constitutes what is called "choke-damp." The craters of volcanoes are always giving out large quantities into the surrounding air. In many natural waters we find it. Those of Vichy in France and others are highly impregnated with it, giving them a

74 The Rare Gases of the Atmosphere

buoyancy and sparkling appearance which is most attractive. We may say that they are almost effervescent in character. If ordinary water be boiled the gas dissolved in it (for there is always a little mixed with atmospheric air) passes away and the quality of the water suffers a change. We get a liquid, dull, uninvigorating and vapid to the taste. The "sparkle" has vanished. It is like soda-water which has been exposed to the air for some time.

Carbon Dioxide forms compounds with lime, magnesia, etc., which occur in great quantities everywhere as natural products, such as Carbonate of Calcium, Magnesium Carbonate and other substances. Examples of the former are ordinary limestone, marble, chalk, whilst the latter includes such compounds as Dolomite (a double Carbonate of Magnesium and Calcium), which gives its name to that beautiful mountain region, the Dolomites, and others. Carbon Dioxide was known to many of the early chemists, Black, Lavoisier, and even to others before them. Black called it "Fixed-Air," and speaks of it as being produced by burning charcoal, etc., and says that "this sort of air is quite distinct from common air."

The gas may be prepared in small quantities by the decomposition of Calcium Carbonate with Hydrochloric Acid. Some pieces of marble or chalk are placed in a flask and treated with the acid. The gas may be collected in a jar by simple displacement of the air therein, since it is very heavy.

We give a diagram (Fig. 17) illustrating the process. Carbon Dioxide is a colourless gas and of high density (1.5 heavier than air) so that some striking experiments may be performed with it. For instance, it may be collected in one jar and then poured out like water into another, and from thence on to a candle, which it will at once extinguish since it does not support combustion. A very small light balloon dropped into a jar of the gas will quietly float on the invisible surface. If an empty jar be weighed on a balance and some gas poured into it, the equilibrium will be at once disturbed, as may be seen by the descent of that arm of the

The Rare Gases of the Atmosphere 75

balance which supports the jar (Fig. 18). And it is owing to its high density that the gas is able to collect in wells and pits, in brewery vats and in caverns.

Carbon Dioxide is poisonous, as we have already remarked, and since it cannot give up any of its Oxygen, it cannot support human life. But, as we shall see in a later chapter (Chap. XXIII), it is as the breath of life to plants; with magic power under the influence of the sun's bright rays they build up their bodies by taking this poisonous gas and decomposing

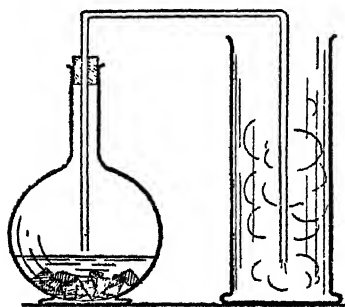


FIG. 17. PREPARATION OF CARBON DIOXIDE FROM MARBLE AND COLLECTION BY DOWNWARD DISPLACEMENT

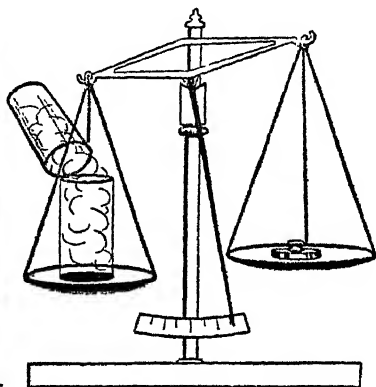


FIG. 18. DISTURBING THE EQUILIBRIUM OF A BALANCE BY POURING CARBON DIOXIDE INTO A JAR

it for this purpose. We set up special apparatus when we want to decompose this gas, and take all manner of pains to collect the products formed by this or any kind of decomposition. The humblest plant does it quietly and regularly, day in, day out, and if we are minded to do so, we may learn by careful observation, all of us, something of its magical ways.

We, too, get Carbon for our bodies by the consumption of vegetable and animal food—an indirect way. By its oxidation the temperature of the body is maintained. There are hidden fires within (if we may so express it) oxidising

76 The Rare Gases of the Atmosphere

the Carbon compounds, and finally returning the gas once more into the air. Take a glass, and after pouring some clear lime-water into it, blow quietly through the liquid with a tube. The result will be a cloudy precipitate of Calcium Carbonate. The Carbon Dioxide present in the breath has combined with the lime to form the white compound seen floating in minute little particles in the liquid.

Carbon Dioxide is slightly soluble in water, forming a solution which is faintly acid to the taste. Under pressure the gas dissolves more freely but escapes once more, as we see in aerated waters, when exposed to the air.

Those who have sat before the glowing cinders of a winter

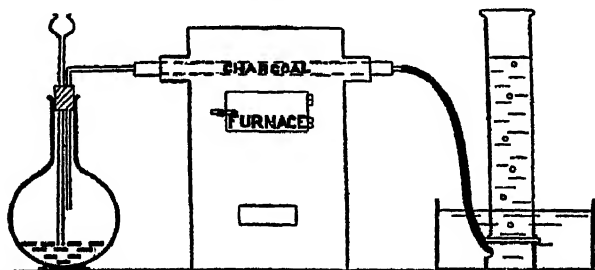


FIG. 19. PREPARATION OF CARBON MONOXIDE BY PASSING CARBON DIOXIDE GAS OVER RED-HOT CHARCOAL

fire, when, having expended their energy in flame and light, the red-hot coals are quietly but surely cooling down, must have noticed pale blue lambent flames playing over the coals and rising up here and there from holes and crannies in the grate. This is Carbon Monoxide, which is formed whenever Carbon burns in a limited supply of Oxygen. We can imitate the action by passing a stream of Carbon Dioxide slowly through a red-hot tube filled with charcoal (Fig. 19) and collecting the gas by displacement of water in an inverted jar. In a low-burning fire of glowing coals, as the air percolates through the red-hot cinders, some of the Oxygen combines with the Carbon and forms Carbon Dioxide. But as this gas gradually passes up through the coals it is decomposed, as in the laboratory method, with the

The Rare Gases of the Atmosphere 77

loss of half its Oxygen, and we get Carbon Monoxide formed at the top of the grate. Meeting with the Oxygen of the air it commences to burn away with the blue flame we all know. At the same time the dissociated Oxygen atoms combine with the Carbon present and form Carbon Dioxide, which passes up the chimney.

Carbon Monoxide gas is colourless and has a density corresponding to that of atmospheric air, in which it is present in small quantities. This is especially the case in our large towns with their factories pouring out dense volumes of black smoke. In such an atmosphere the proportion of the gas present in the mixed gases may rise as high as 4·5 per cent of the total volume. Escaping into the air from the factory chimneys it renders it very poisonous to the human system.

What happens is this. The gas has a peculiar action upon the blood, taking away some of the Oxygen and forming with the Hæmoglobin a substance called Carboxy-hæmoglobin. Our blood is full of little minute corpuscles about $\frac{1}{2500}$ of an inch in diameter. Inside them and enclosed by a thin membrane is the red pigment (Hæmoglobin) which gives to blood its characteristic colour. And it is on these little particles which play so important a part in the distribution of Oxygen through our bodies by their action on the blood that Carbon Monoxide exercises such serious influences. If we pass water in the form of steam over any form of Carbon—charcoal for instance—we get a gas given off which is a mixture of Carbon Monoxide and Hydrogen. When we come to study Hydrogen we shall see that it, too, is an inflammable gas, burning with a pale blue flame. And since we have seen that Carbon Monoxide burns in a like way, we can imagine that a mixture of these gases would produce an exceedingly inflammable gas, but one with little illuminating power. This is so, and the gas is called “Water-gas.”

Carbon Monoxide is a strong deoxidising agent. It takes away Oxygen from any substance such as an Oxide and reduces it. Advantage is taken of this fact in the smelting

78 The Rare Gases of the Atmosphere

of iron. Air is blown through a mixture of Iron Oxide and coke. The Carbon Monoxide (as in a grate) takes away some of the Oxygen in the Oxide to form Carbon Dioxide, and the iron melts and is collected in suitable moulds.

We have in the preceding chapter (Chap. vi) examined some of the properties of the ordinary gases of the atmosphere, such as Nitrogen and Oxygen. We also saw that the air always contains small quantities of other constituents, such as Ozone, Carbon Dioxide and Carbon Monoxide, Aqueous Vapour, etc.; and in this chapter we have looked a little more closely into some of the properties of the two Oxides of Carbon, which we were unable sufficiently to do in the last chapter. We thus see that the air which we breathe is not so simple as some people might imagine it to be. It is a gaseous mixture of most interesting constituents.

Up till recent times it was thought that there were no further discoveries to be made with regard to the constitution of atmospheric air. It was supposed to be a mixture of the gases which we have studied, together with additional traces of impurities already mentioned. But the possibility of other constituents being present was never lost sight of. Then came the news that another gas had been discovered by Lord Rayleigh and Professor Ramsay. They found traces in the air of an element to which they assigned the name of Argon, because of its inert character (*argon*, lazy, Grk.).

Lord Rayleigh, after being engaged in determining whether the ratio of the atomic weights of Oxygen and Hydrogen relative to each other was as 16 to 1, conducted further experiments on the same lines. Oxygen was prepared in several ways, and the figures which he finally arrived at worked out accurately in accordance with the determinations made before by other experimenters. Then Nitrogen was examined from different sources, and here a discrepancy was noted. Lord Rayleigh found that Nitrogen prepared from Ammonia was lighter than the ordinary Nitrogen of the air, the deficiency in weight amounting to about 1 in 200. This curious fact was

The Rare Gases of the Atmosphere 79

subjected to different forms of experimental investigation in order to discover the reason.

Professor Ramsay, in some experiments which he had been conducting with Hydrogen and Nitrogen in order to cause them to combine, had occasion to pass Nitrogen over heated Magnesium, and noticed that the metal absorbed it quite appreciably. He applied the same process to the Nitrogen of the air, and after absorption had taken place, he found that a small quantity of residual gas remained. It was weighed and showed an increase in density. Fresh experiments were now made. Was there some hidden constituent which had so far escaped detection in atmospheric air? The investigations were conducted on an extended scale and with the utmost degree of refinement. They left no doubt, at the conclusion, that there really was another

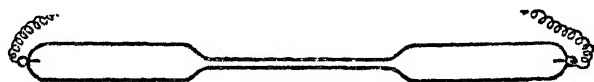


FIG. 20. TUBE USED FOR EXAMINING THE SPECTRA OF GASES

constituent present, though in minute quantities, in the air we breathe. A small quantity of the precious gas was sealed up in a tube employed for the study of the spectra of gases, and subjected to spectroscopic examination.

The tube (Fig. 20) has its two ends connected by a very fine bore called the capillary portion, and when the electrodes or terminals are connected up to a Ruhmkorff coil, the spectrum of any gas which has been previously introduced into the tube will on illumination exhibit various characteristic coloured lines. The gas becomes incandescent by the action of the electric current and discloses its identity. Thus Nitrogen reveals in the slender capillary tube (for this is where the spectra are obtained) a complicated spectrum of a number of lines of different colours. A characteristic and beautiful spectrum is furnished by Helium, consisting of a brilliant yellow line and fainter lines in the red, green, blue

80 The Rare Gases of the Atmosphere

and violet (Fig. 21). Now Professor Ramsay found that in addition to the Nitrogen lines which appeared in the spectrum of the gas examined, there were several which had not before been detected. They were situated in the red and green portions of the spectrum. It was the spectrum of the new gas which after further investigation was found to be, beyond all doubt, a new constituent of the air. Great interest was displayed when the discovery was announced, and the properties of the new gas were eagerly examined.

Argon exists only in minute quantities in atmospheric air, in amount about .937 per cent. It exists also in many mineral waters and springs, such as those of Bath and other places, also in some continental waters. Its properties are such as to include it amongst those peculiar gases which, from a chemical point of view, are so inert and inactive that

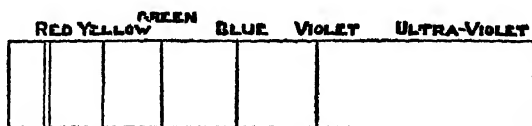
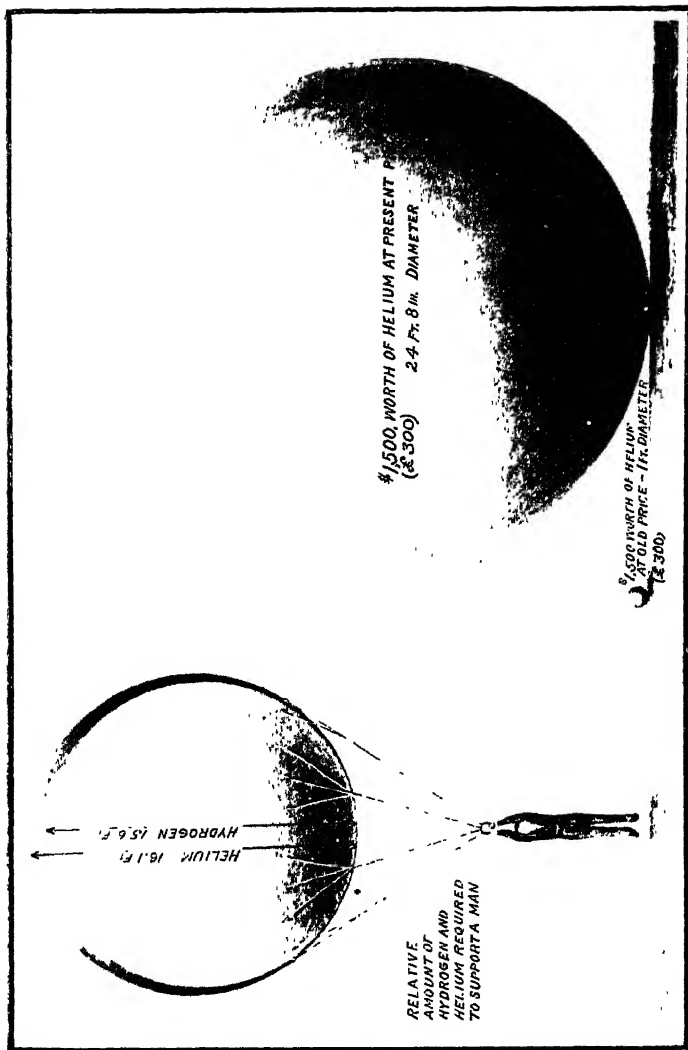


FIG. 21. SPECTRUM OF HELIUM

in the Periodic System of the Elements they occupy a column by themselves. They do not form any chemical compounds. Argon refuses to combine with Oxygen, Hydrogen and Chlorine even in the "nascent" state. The atomic weight is 39.88. It has been liquefied.

After the discovery of Argon endeavours were made in order to find out whether there were any other undetected constituents of air. An examination of the spectrum of the sun in a solar eclipse disclosed the presence of a bright yellow line in the Hydrogen spectrum, which at first was supposed to be identical with the D line of Sodium (Chap. xviii). Its position, however, was further in the direction of the blue end of the spectrum. Was it, it was asked, a new undiscovered body, or merely a modification of Hydrogen? It was on further examination considered to be a new constituent of the sun's atmosphere, and the name



HELIUM IN AIRSHIPS.

By reason of cheaper methods of production and its non-inflammability, Helium as a substitute for Hydrogen is to-day being seriously considered.

The Rare Gases of the Atmosphere 81

Helium (*helios*, sun, Grk.) was given to it. It did not appear to exist in the air nor in any terrestrial ore. In 1895 Ramsay found that Clèveite, one of the rare minerals, gave the spectral lines of Helium when treated with Sulphuric Acid. The same substance more than 92,000,000 of miles away had given the same spectrum, and we know now that it is to be found not only in the sun, but also in stars and nebulae. And on earth it has been discovered in the waters of different spas, both at home and abroad, as well as in certain minerals like Monazite, Yttrium ore, and Fergusonite. It is present in the air only in very minute quantities—1 to 2 parts per 1,000,000. It is incapable of combining with other bodies, and is thus classed with Argon and the other members of this group of inactive gases.

Now when Radium was discovered, and investigators all over the world were examining the properties of this extraordinary element, it was soon found that it gave rise to three distinct forms of radiation,

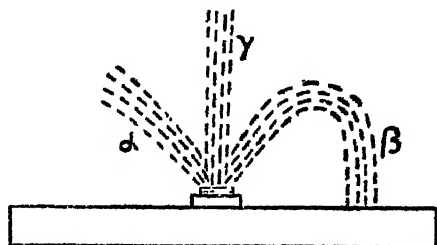


FIG. 22. SORTING OUT THE RADIATIONS EMITTED BY RADIUM BY MEANS OF AN ELECTRO-MAGNET

tion, the alpha, beta and gamma rays. The first of these with which we are the more immediately concerned were found on critical examination to consist of a swarm of minute particles, each carrying a positive charge of electricity. They issued forth with a speed about $\frac{1}{10}$ of that of light. Mme. Curie found that they could be separated from the other rays. Under the influence of an electro-magnet, the alpha and beta rays are deflected in opposite directions, whilst the gamma rays pursue their path unaltered (Fig. 22). Thus each type of radiation can be examined. Rutherford made the suggestion that these particles, the alpha rays, were really atoms of Helium. Later on he conducted a series of experiments with Geiger which finally established the truth of his

82 The Rare Gases of the Atmosphere

supposition. Then Ramsay found that Radium preparations evolved Helium when they were dissolved in water. And we must remember that most of the ores which have proved to be a source of Helium have also revealed the presence of radioactive bodies within them.

Then came the brilliant series of investigations by Ramsay and Soddy which finally established beyond question that the Emanation of Radium—that mysterious gaseous substance—was all the time disintegrating and breaking up into another wonderful body—Helium! The experiments which established this profound fact were triumphs of manipulative skill and ingenuity. Later researches confirmed these results. Rutherford and Royds in an admirable piece of work succeeded in enclosing some of the Emanation in a glass bulb whose thickness was of the order of less than $\frac{1}{1000}$ of an inch. This was enclosed in another bulb, which was exhausted to a high degree. The alpha particles given off were able to pass through the walls of the inner bulb by reason of their extreme thinness, and on spectroscopic examination the spectral lines of Helium were observed in the outer bulb. A control experiment in which only Helium was present in the inner bulb gave no result. It thus appears that the alpha particles are atoms of Helium, and that the Emanation breaks down and changes into another element. The Emanation changes into another element! What would the old Alchemists have said if they could have seen the wonders of this age, and with their own eyes witnessed the transformation of one element, Radium, into the Emanation and thence into another element, Helium? It was not for them, but for a later age to witness these marvels. Yet, in season and out of season, the Alchemists preached Transmutation. What would they have said if they could have seen the Mysteries of Radium?

After the discovery of these new constituents of the air, further search was made in order to find out other possible—but so far hidden—gases. And again success crowned the efforts of the investigators. Ramsay and Travers from liquefied air, originally supplied by Dr. Hampson for the

The Rare Gases of the Atmosphere 83

purpose of reducing Argon to the liquid state, succeeded in obtaining a minute quantity of another inert gas which they called Krypton (*kruptō*, to hide, Grk.). Its spectrum revealed two bright lines in the yellow and green portions of the spectrum. It is entirely inert and takes its place with the other rare gases, as predicted by Ramsay.

Neon, another rare and unsuspected constituent of the air, was discovered by liquefying Argon and then allowing the liquid to evaporate off. The gas which came off at any early stage of this operation was found to give, when examined in the spectroscope, a series of lines which had not been observed before. They were evidently those of another new gas, another constituent of the air. The name given to it is a derivative from the Greek *Neos*, new. Here again we have another inert gas, and we include it amongst the others. It exists in the air only in minute quantities, 1 in 200,000.

Xenon, an extremely rare constituent of our air (1 in 20,000,000), was discovered by Ramsay when engaged in a series of delicate and tedious operations with the object of preparing the new gases on a somewhat larger scale than before. Its name is derived from the Greek *Xenos*, a stranger. It is included amongst the other inert gases of the atmosphere.

It has long been known that an electrified body, such as an Electroscope, which has received a charge of electricity, is unable to keep this charge indefinitely. Gradually but surely, little by little, the instrument loses its charge. This we depict in the annexed illustration (Fig. 23), where the gold leaves under a charge and in their normal condition are seen. The leaves are attached to a wire terminating in a ball or plate which is highly insulated. Under the influence of an electric charge, the gold leaves separate and stand out

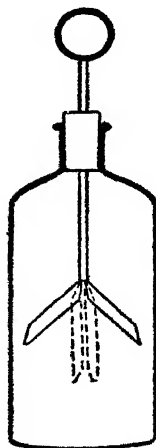


FIG. 23. ELECTROSCOPE UNDER THE INFLUENCE OF AN ELECTRIC CHARGE

The dotted lines show the normal position of the gold leaves.

84 The Rare Gases of the Atmosphere

from each other. In normal conditions they hang down vertically. The air is not a complete insulator. What is it which robs the electroscope of its charge? Something capable of rendering the air a conductor (Chap. XVI).

The story of Radium gives us the clue and the answer to this mystery. There exists in the air we breathe minute traces of another gaseous substance which we call Niton. It is the Emanation of Radium. And the varying conductivity of the air, for it is not the same in all places, depends upon the amount of this wonderful substance present in it. The radioactive bodies present in the earth, although in minute quantities, are the source from whence the emanation passes into the atmosphere. And not only the rocks and soil of the earth's crust, but also springs are sources of radioactivity. We know that Helium, as we have already seen, has been discovered in many mineral waters and hot springs, and its presence there indicates also the presence of Radium. And this may account, too, for the medicinal effects which have rendered so many waters famous. Some of them, especially those on the Continent, are almost chemically pure, but are distinguished for their high emanation content. Hot springs are found to be more radioactive than cold, and although there may be resemblances between individual springs from a chemical point of view, yet such often exhibit different radioactive powers.

The discovery of Radium and the phenomena of radioactivity have revealed to us, amongst other wonderful things, yet another constituent of the air which we breathe into our lungs every moment of the day.

CHAPTER VIII

IN FROZEN WORLDS: MARVELS OF LOW TEMPERATURES

THE three states of Matter—solids, liquids and gases—are familiar to us all in the form of ice, water and steam. And of these water, a liquid, seems to us to be the most natural form of the three. But iron or any other metal is familiar to us as a solid, and we are apt to forget that it may exist in a liquid and vaporized condition. So, too, the air we breathe, or indeed any gas like Oxygen or Nitrogen, are known to the majority of people only in the gaseous condition, and it is too often assumed that there can be no other state. That is the mistake into which the early chemists fell. They could not imagine that a gas like Hydrogen could exist in the solid and liquid states. We know to-day how erroneous those ideas were, for all gases can be liquefied and reduced to the solid state under certain conditions. We look at water, iron, oxygen in terms of their normal states. But we must not forget that there are other states in which these forms of matter are capable of existing—but in an abnormal condition. There are only two methods by which gases can be compelled to assume the liquid state—by compression, and by extreme cold. The efforts of the early investigators were attended only with partial success. Such gases as Chlorine, Sulphur Dioxide, Ammonia, and one or two others which are easily liquefied, naturally claimed their attention. And it is interesting to compare the methods employed in those early days with those which obtain to-day.

Faraday took a strong glass tube bent round in the form of an inverted U, and putting some Ammonium Carbonate

and Sulphuric Acid in it he heated one end and put the other into a freezing mixture. He thus liquefied Carbon Dioxide by its own pressure; and he treated other gases in the same way. But it is evident that apparatus such as this would sustain no great amount of pressure, and might be a source of danger. Faraday was moreover confronted with a peculiar obstacle which lies at the root of the whole matter. If a gas be compressed it cannot be liquefied unless its temperature stands at a certain degree. This is called the Critical temperature of the gas. Above this you cannot liquefy a gas by simply compressing it. But you may lower the temperature much below this point, and at the same time a less pressure will be required.

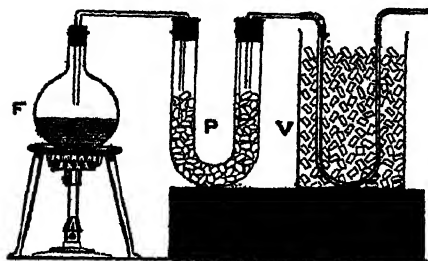


FIG. 24. LIQUEFACTION OF SULPHUR DIOXIDE GAS

Thus, the critical temperature of Carbon Dioxide Gas is about 31°C ., and a pressure of over 70 atmospheres is required to liquefy it at that degree. But if it be cooled to 0° , a pressure of 36 atmospheres is sufficient. The so-called "permanent gases" like Oxygen,

Hydrogen etc., have so low a critical temperature that in order to liquefy them by compression it would be necessary to cool them down several hundreds of degrees below zero. But under the combined influence of pressure and a very low temperature all these gases have been liquefied.

One of the easiest gases to liquefy is Sulphur Dioxide. The gas is generated in the ordinary way in a flask, F. (Fig. 24), passed over pumice stone and Sulphuric Acid in order to dry it, P, and then into a vessel surrounded by a freezing mixture of ice and salt, V, where it condenses to a light mobile liquid. By cooling it down to a temperature of about 80° , it can be solidified to an ice-like mass.

In the early days it was impossible to cool some gases sufficiently, and equally impossible to apply the requisite

pressure owing to the want of suitable apparatus. But Cailletet, by adopting a new principle which underlies all modern work in this direction, was enabled to go further than the earlier investigators. The principle is this. If a gas be compressed strongly under enormous pressure and then suddenly allowed to expand and escape by a small orifice it becomes intensely cooled. Oxygen under a pressure of 4500 lb. to the square inch assumed the appearance of an "opaque fog." Pictet working on these lines met with still greater success. He took Oxygen and submitted it to the enormous pressure of 4800 lb. to the square inch, and then cooled it by the rapid evaporation of solid Sulphur Dioxide and Carbon Dioxide. The result was that the Oxygen assumed the liquid state. Then Ethylene and Nitrogen succumbed, and after atmospheric air had been liquefied by Olszeuski, Hydrogen was reduced to the liquid state in very small quantities. Then Nitrogen was obtained in the solid state. Before, it had appeared in "snow-like crystals." Now, at a temperature of -225°C . it was an absolute solid. Solid Carbon Dioxide is an interesting substance. It presents a white snow-like appearance—artificial snow in fact—whose temperature is below the freezing-point of water by as much as 140°F . Pressed into rods, this icy substance has been used in the treatment of skin eruptions and blemishes.

In England, Professor Dewar, who has carried out some remarkable researches into the frigid regions of very low temperatures, was the first to liquefy air. With the help of compressed Nitrous Oxide Gas and liquid Ethylene, which was allowed to evaporate suddenly, he produced an extreme degree of cold, and not only liquefied air, but reduced Oxygen to the state of a pale blue fluid. He then liquefied Hydrogen, and allowing it to evaporate he got the amazing result of solid air. It appeared at first as a stiff transparent jelly which could only be examined in a vacuum or in an atmosphere of Hydrogen. It melted immediately on exposure to air, and in doing so caused some of it to liquefy. The liquefaction of Hydrogen was a great feat, but when he

announced in a simple message to Sir W. Crookes that he had liquefied Helium (and thus produced 468° F. of frost) there was universal satisfaction that his researches had been so signally rewarded. Dewar also solidified Hydrogen, but not Helium. This achievement was the work of Professor Onnes, of Leyden, who, telegraphing to Professor Dewar the good news, said, "Converted Helium into solid." Thus was the crown put to that long series of researches carried on for so many years. By an extension of the principle of compression already mentioned, a further impetus was given to the production of liquid gases on a large scale.

Ordinary air, after being subjected to a high compression, was passed through a coil of pipes cooled by water, and was then allowed to expand through an orifice. It became very cold and was then allowed to pass round the coil of pipes in which it had been confined, thus reducing the temperature within. The air on expansion caused a further reduction in the coil. Thus the pipes were progressively cooled to a lower and lower temperature so that finally liquid air could be drawn off. In this way Tripler, of New York, produced a large quantity of the fluid by comparatively simple means.

Other investigators have produced apparatus on similar principles.

Dewar made liquid Oxygen, and kept it in a special vacuum vessel "as a stiff transparent jelly" for some time. It appeared to be solid Nitrogen mixed with liquid Oxygen.

Hampson used an apparatus made by the British Oxygen Co., which was simple and exceedingly efficient. Linde and Claude produced machines for liquefying air on a large scale.

Other gases besides air are daily liquefied on a commercial basis, and on a scale which was scarcely deemed possible in the early days. I am indebted to the Liquid Air and Rescue Syndicate, Ltd., of Park Royal, Willesden, for many interesting particulars concerning the production of liquid gases on modern lines. Let us take ordinary air as an example

The air is first of all freed from moisture and Carbon Dioxide. This is done by drawing it through a vessel A (Fig. 25) by means of a compressor. The air enters at the bottom and is drawn out at the top after passing through the absorbing agent—Caustic Soda solution—which, falling from the top to the bottom, meets the air and absorbs the Carbon Dioxide. The air freed from Carbon Dioxide is drawn into the air compressor, which compresses it to a

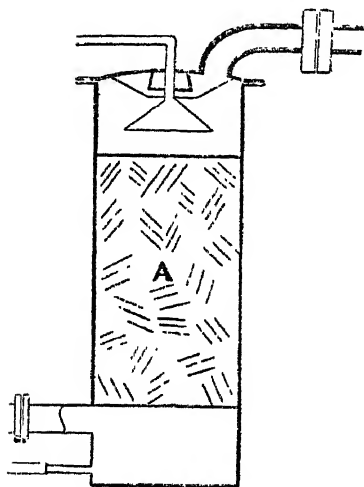


FIG. 25. PURIFIER

By permission of Messrs. Liquid Air, Ltd.

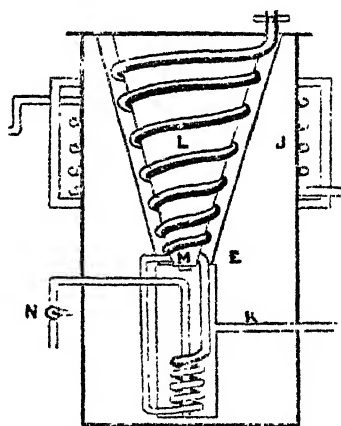


FIG. 26. AIR LIQUEFIER

By permission of Messrs. Liquid Air, Ltd.

maximum of 200 atmospheres (2950 lb. to the square inch). It is then cooled to remove the heat of compression and then thoroughly dried. It is now ready to be liquefied. The apparatus for this purpose consists of the liquefier E (Fig. 26) and an expansion engine. Part of the air passes through the air-cooled coils J on the outside of the liquefier and is then expanded down to a low pressure by the engine. It thus becomes very cold—below the critical temperature. Entering the liquefier at K it rises through the heat exchanger L. This contains a number of small pipes, through

which the other part of the compressed air passes downwards and gives up its heat to the rising air from the expansion engine. It now reaches the expansion valve M greatly reduced in temperature, but still at high pressure. This air is expanded through the valve at about atmospheric pressure and thus is further cooled. The cold air meets with the air from the expansion engine and so is cooled still more. Thus the air reaches the expansion valve at a temperature which is being continuously reduced until on expansion a part is liquefied. This collects in the bottom of the apparatus and can be drawn off at N.

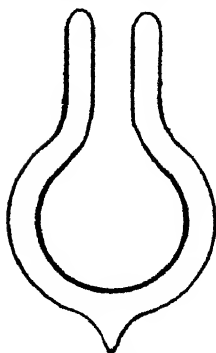


FIG. 27. VACUUM
VESSEL

In order to keep liquid air for any length of time it is necessary to store it in special vessels since the evaporation is so excessive. A very convenient vacuum vessel was introduced by Dewar for this purpose. It consisted of two flasks, an outer and an inner (Fig. 27), with a space between which was highly evacuated of all air so that heat could not pass in from without. A coating of Silver was placed on the exterior walls of the two vessels in order to increase the effect of the high vacuum. The modern Thermos flask is made on the same principle.

Glass vessels are of necessity very fragile, often breaking without any apparent reason. They can only be made in small sizes and are wasteful in the process of evaporation. Metal containers introduced by the Liquid Air Syndicate are more durable and easily handled. They can be made in any size, and evaporation is reduced to a minimum.

Liquid air is extensively used in rescue work in mines. It contains 60 per cent of Oxygen, and expands to about eight hundred times its volume on evaporation, so that it is a means of carrying air in a very condensed form. The "Aerophor" apparatus constructed by the Company already alluded to is a clever and adequate breathing dress, which demonstrates not only one of the modern and useful applications of air

in a liquid state, but also its adaptability to work of an urgent character carried on for the most part under abnormal conditions. A glass full of liquid air is in appearance very much like water, but its pale blue tint, which becomes darker if the liquid is allowed to evaporate, tells us that it is not quite the same. Its properties are highly interesting.

The temperature of liquid air is exceedingly low, being about 312° below zero Fahrenheit. Most people when the word "zero" is mentioned in connection with temperature, have visions of the thermometer sinking to icy depths under the influence of an iron frost. The expressions "20° below zero" or "50° of frost," etc., make us instinctively shiver, while any lower degree of cold reminds us of Siberian winters or the horrors of Polar expeditions. But here is ordinary air, chained and imprisoned, squeezed and compressed, and then chilled to an exceeding coldness, so cold, in fact, that ice is warm, a glass of cold water positively hot, and the temperature of an ordinary room a furnace compared with it.

A glass of liquid air boils vigorously away all the time, its outside becomes covered with an icy layer of frost, while clouds of moisture condensed from the surrounding air descend and envelope the glass. It was shown by Tripler, of New York, in a remarkable series of experiments, some of which were described in the "Cosmopolitan," that it is possible to thrust one's hand into the liquid provided that it is withdrawn at once. A slight sensation of coolness is all that is experienced. A thin layer of air forms a kind of protective cushion. The experiment recalls the classic one of plunging a moistened finger into molten lead where a thin covering of vapour affords immunity from harm. In both cases "burns" result from a careless method of performing these sensational experiments.

If a lump of ordinary ice be taken and a can of liquid air placed upon it, it might well be some red-hot stove, for the liquid begins to boil vigorously, and hoar-frost covers the surface of the vessel.

In one of his experiments Tripler took a can of liquid air

and heated it over a Bunsen-burner (Chap. ix). It began to boil away of course vigorously, while a coating of ice covered the surface of the can, the bottom included ! The cold produced by the increased evaporation was so great that much of this ice consisted of solid Carbonic Acid Gas as well as Aqueous Vapour derived from the surrounding air. The heat of the flame was powerless to prevent it. A lump of ice caused the liquid air to boil much faster. As he says, it was " as if I had thrown in a hot stone ! " But the addition of water caused the vessel to boil over, while the water instantly turned to ice.

Dewar, at the Royal Institution, in one of his lectures, conducted some remarkable experiments. He showed that many bodies, particularly metals, became exceedingly brittle when immersed in liquid air. An india-rubber ball lost its power of rebounding and struck the ground with a metallic sound ; metal springs became hard and rigid ; metal vessels, especially those of iron, steel, tin, etc., became exceedingly brittle, and were liable to break in pieces when dropped on the ground, like glass. Many bodies under the influence of the low temperature behaved in a very interesting way. They commenced to shine with a beautiful phosphorescent light ! Candles, eggs, a ball of ivory, and other objects, all became self-luminous. The ivory ball, after immersion in liquid air and then illuminated by the rays of an arc lamp, was especially beautiful with its green phosphorescence. White of egg is very luminous, also white flowers. Dewar also demonstrated the magnetic character of the liquid, for it was attracted to the poles of a powerful magnet. Faraday showed that Oxygen was magnetic, and liquid air, of course, contains a large amount of that element. If a piece of Steel, spring-tipped with Sulphur and ignited by a match, be dipped into the liquid, it will continue to burn brightly.

By cooling the outside of a vessel with liquid air and repeatedly dipping it into water, Tripler made an ice-cup, in which he burnt some Steel wire, recovering afterwards bits of molten metal from this crucible of ice.

If there is one thing which the early chemists thought was incapable of being frozen, it is alcohol. Everything else might succumb, but alcohol—never! To-day, we know that whisky and brandy can easily be frozen by pouring liquid air into a glass containing these substances. And by special means even pure alcohol itself may be frozen.

Mercury is easily frozen. If a quantity be placed in a paper mould and screw-eyes fixed at the end, liquid air will convert it into a solid. To one of the eyes a cord may be attached, and a weight of many pounds suspended from the other.

Liquid Oxygen has been used in aeroplanes flying at high altitudes in order to counteract the evil effects produced by the rarity of the air. An article in a recent number of the "Lancet" by Dr. Birley, C.B.E., gives some interesting particulars of the use of Oxygen in this connection during the late war. As the conflict proceeded, and especially during the later stages, the vital importance of reconnaissance and other work at increasing altitudes from 15,000 feet upwards, raised problems which it was necessary to solve. Up to this height, and for short flights at greater altitudes, our airmen suffered no great inconvenience. But long flights at anything over 15,000 feet produced marked physiological effects, such as a desire for sleep, unsteady gait and a feeling of exhaustion, the results due to a want of Oxygen. And the higher the altitude attained the more pronounced are the effects. At the level of 14,000 feet only, the percentage of Oxygen corresponding to its measurement at the level of the sea falls to nearly one-half.

The quantity of Oxygen required to counteract the effects mentioned above depends upon the altitude attained by the pilot and observer, and the volume of air breathed per minute. The average volume when a man was sitting still was a little over 7 litres (a litre=1 pt. 15 oz.). This rose to over 18 litres at a walking pace of two miles per hour. An observer using his gun did an amount of work equivalent to this degree of exercise, and a supply of Oxygen corresponding to a work-equivalent of breathing 20 litres per

minute (a little over 2 miles per hour) was deemed sufficient. As a matter of fact, the amounts supplied were found quite sufficient up to altitudes of 20,000 feet and over. But it was clearly proved by practical demonstration that reconnaissances of several hours' duration could not be carried out at the great height of 20,000 feet without an adequate supply of Oxygen gas. In its absence the value of the results obtained were much discounted, and the number of men who were able to do useful work at that height rapidly dwindled. The great difficulty lay in the apparatus employed for the purpose of providing the airmen with the additional gas required. A mask over the mouth and nose did not appeal at all to a man anxious for a fight with the enemy at close quarters. At these critical moments even goggles and helmets appeared to be unnecessary.

If it be true that to a man breathing quietly in a normal manner the percentage of Oxygen in the air we breathe (about 20 per cent) is sufficient, it is also true that increased exertion, especially at high altitudes, gives rise to symptoms of nausea which to airmen are a positive source of danger. In the light of this, the use of Oxygen gas as an inhalant is of great interest and importance.

CHAPTER IX

THE STORY OF FLAMES—COMBUSTION

THE fire which burns in our grate, the gas which illuminates our room, the humble candle which was all our ancestors had to rely upon in the past, are all examples of Flames or gaseous vapours which by chemical combination with the Oxygen of the air are rendered so hot that they pass into a state of incandescence.

If we take an ordinary candle and examine the structure of its flame carefully, and see what happens when the candle is burning, we shall find much that is of interest in our inquiry, and much, too, that will help us to understand what the term "flames" really means. The wick of a candle is surrounded by wax, and when it is lighted it draws up the melted wax in the form of oil. This burns away with a degree of brilliancy depending very much upon the nature and composition of the wax composing the candle. If it be very pure and of high quality, the brightness of the light is much increased.

The oil passes up into the wick of the candle by a very beautiful action known as "Capillary attraction" (*Capillus*, hair, Lat.). By this means the oil is lifted up, as it were, through the little holes and interstices of the wick, just as water is absorbed and drawn up by a piece of blotting paper. If a tube of glass be drawn out when heated to redness, its bore may be rendered excessively fine. If immersed in water the force of cohesion produces a surface tension of the film, and the water is drawn up the tube. So, too, in our bodies there are numbers of minute little tubes of microscopic dimensions called Capillaries, through which the fluids of the body circulate.

The Story of Flames

The flame of a candle is really divided into four entirely different parts, as may be seen by inspecting the accompanying diagram (Fig. 28). In the centre is a dark zone or region, D, which consists of a quantity of gas in a state of comparative coolness, and therefore only partially burnt. This region closely surrounds the wick. Now, just under this zone there is a much smaller portion which is blue in colour, W, and consists of the products of the burning of the wick. Immediately above the dark part of the candle flame is



FIG. 28. CANDLE FLAME AND ITS STRUCTURE



FIG. 29. COLLECTING AND BURNING GASES FROM A CANDLE

the luminous portion L. This consists of gases and vapours which are not in a complete state of combustion. There is consequently present a quantity of unburnt Carbon in addition to that which gives to this area its luminosity. This can be detected by introducing a piece of cold metal or porcelain, which at once becomes coated with a deposit of soot or Carbon in a fine state of division.

Looking again at the diagram, we see another zone at H which is not so luminous by a great deal as the part beneath it. All the products

of the combustion of the wick and wax are here raised to a high temperature by complete combination with the Oxygen of the air, producing thereby a high state of oxidation. And, as we may imagine, this part of the flame is very hot.

That there is a quantity of gas present in the dark portion of the flame D which is not completely burnt is seen by the following pretty experiment. We carefully introduce into this area a tube of glass, and keeping it steadily in this position, we take a match and ignite the gas which now escapes from the dark zone (Fig. 29). It is somewhat

astonishing, no doubt, to those who have not seen this before that there should be this amount of combustible gas within a candle flame, but from our experiment we know that sufficient air cannot be present to ensure complete combustion, and this is exactly what is necessary if all the vapour is to be burnt.

From what we have seen so far in studying the flame of a candle, we may divide flames in general into two main divisions—luminous and non-luminous. Flames which are very luminous are those in which there is a large amount of Carbon present, and this being raised to a very high temperature becomes by this means very illuminating. There is not a complete oxidation of all the Carbon present. There are a number of little particles of unburnt Carbon which give to the flame its brilliancy. When they become white-hot they radiate forth light of great intensity.

Take the case of ordinary coal-gas. It contains amongst many other constituents several gases which individually burn with a more or less bright flame, and it is these which give to the gas its illuminating power.

One of the gases present in coal-gas, a Hydrocarbon as it is called, or one consisting of Carbon and Hydrogen, is Olefiant-gas or Ethylene. The other is that well-known gas, Acetylene. We have therefore present two well-known gases which contribute to the luminosity of coal-gas and which both contain Carbon in their composition. Acetylene has not only a very disagreeable smell of itself which is far from pleasant, but it burns with a bright smoky flame. And when we come to consider that coal-gas contains also other illuminating Hydrocarbons, we see that its luminosity must be due to the imperfect combustion of all these Carbon compounds.

Since there is incomplete combustion, there must be present countless numbers of little particles of Carbon which render the gas illuminating. The deposit of soot on a piece of white porcelain, as we have already seen, is a proof of this. A curious fact has been observed concerning this question of the luminosity of flames. If a candle be taken

to the top of a very high mountain the luminosity of its flame will be considerably diminished. The clue to this mysterious behaviour of a flame which apparently is burning away in other respects as if it were at a lower altitude, lies in the fact that the denser a gas is, the more luminous is its flame. On the mountain top, therefore, where the air is highly rarefied, we can imagine that the density of the gaseous vapour of the candle would be decreased accordingly.

Heat, too, has an effect. The hotter a flame is, the greater is its luminosity. Beyond a certain temperature, of course, the reverse would obtain, since the little particles of Carbon would be completely burnt up with a diminution in the illuminating power of the flame as the natural consequence. Suppose that we burn a little Sulphur in the air. What do we see? Just a little pale blue flame which gives off suffocating fumes of a gas called Sulphur Dioxide. Now take a jar of Oxygen and place some of the burning Sulphur within it on a deflagrating spoon. At once we get a totally different form of combustion. The Sulphur burns now with a brilliant blue-violet light, and there is a considerable evolution of heat. The difference is very marked.

Let us look now into the question of flames which are non-luminous. The pale blue flame of a spirit-lamp or of Hydrogen is not only intensely hot but of low illuminating power. If, however, the flame of a spirit-lamp be turned up very high it becomes a little more luminous owing to the combustion being less complete.

If we introduce into any non-luminous flame, such as that of a spirit-lamp, a substance which does not burn away in the flame, but which still retains its solid state, we at once cause the flame to become luminous. Thus, if we place in it a small piece of lime or chalk it will cause the flame to become brighter, for the chalk will become incandescent and will begin to give out light and heat. Or if we blow into the flame some finely divided charcoal its luminosity will at once be increased. We have given to the flame by artificial means a quantity of those little Carbon particles which the

flame of a candle naturally possesses. If we introduce a substance which does not consist of little particles but is solid throughout like Platinum wire, we again get luminosity as before. The wire will glow strongly and the flame will present quite a different appearance.

This is the principle of what is called Lime-light. Lime is a very refractory substance. It does not burn away if we strongly heat it, but becomes white-hot and glows with an intense light. Even in a spirit-lamp, as we have seen, it becomes quite bright and luminous. But if we expose it to the influence of a mixture of Hydrogen and Oxygen gases, which have far greater heating powers than the mere flame

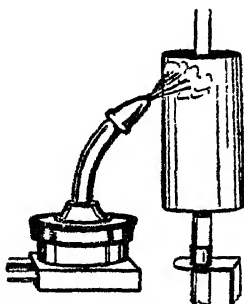


FIG. 30. LIMELIGHT



FIG. 31. CANDLE EXTINGUISHED BY A COIL OF WIRE.

of a lamp or candle, we shall get a light of the greatest brilliancy. A stream of Hydrogen gas at a moderate pressure burning with a hot pale flame is mixed with Oxygen which is forced or "blown" through it at a high pressure. These combined gases impinge upon a cylinder of unslaked Lime (Fig. 30), which is thereby raised to incandescence. Such a light is equal to about 250 candle-power.

In all flames there is a limit of temperature below which the constituent gases and vapours are not sufficiently heated in order to secure free combustion. This we have already seen in the case of a candle. The hottest part of the flame is at the top where the chemical action is greatest. There is

plenty of air to supply the requisite amount of Oxygen, and accordingly we get high temperature and high combustion at that point. If a flame be cooled down very much it will become less bright or even be extinguished. Thus if a coil of wire be placed over a candle (Fig. 31) it will put out the flame. The wire cools down the burning gases, abstracts some of their heat, and thereby renders them unable to maintain combustion.

If instead of a coil of wire we make use of a piece of very fine copper gauze and place it over a jet of coal-gas we shall notice a curious effect. When we light the gas we shall find that it will burn only *above* the gauze. Below, the gas is so cooled down by the conducting power of the gauze that its flame is extinguished. Above, it becomes more heated until it is raised to the requisite temperature for ignition.

The "Safety-lamp" of the coal miners, or the Humphry Davy lamp as it is called, works on the above principle. In all mines there is always the risk of the air becoming dangerously augmented with a considerable quantity of Marsh gas (Methane) or Fire-damp, which forms an explosive mixture. The "Safety-lamp" was invented to prevent those disastrous explosions which even in these days occur in the best managed pits.

The lamp (Fig. 32) consists (in its original form) of a container for oil with a gauze cylinder surrounding the flame. On the principle of the experiment we have already described, the action of the lamp when it is brought into an explosive mixture of gases is as follows: No flame can pass through the wire guard from within and thus inflame the explosive mixture of gases without.

Of late years Acetylene has been used in miners' lamps with success. Also electric light lamps with bulbs placed in the focus of a parabolic mirror, thus giving a concentrated beam of light. And there are special screens provided with various safeguards so that the risk from inflammable gases may be reduced to a minimum.

If we take a gas-jet and introduce into it some air we shall cause more complete combustion to take place, but

the luminosity of the light will decrease. If the air be admitted in the right proportion, we shall be able to change our bright luminous flame into one which is quite blue in colour and intensely hot. We have supplied it with more Oxygen. It is the principle of the Bunsen-burner so much used in laboratories. Air is caused to enter the base B (Fig. 33) by a number of little holes, H. It then passes up the main tube T and mixes with the gas supplied through the pipe P. The consequence is that we get a mixture of air and gas at the top, which can be ignited. It burns with a very hot flame with very little Carbon in it, and it is colourless and clean to use. If, however, the little holes be closed,

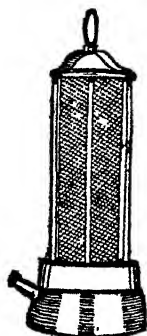


FIG. 32. MINER'S SAFETY LAMP.

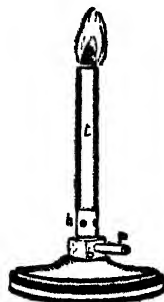


FIG. 33. BUNSEN BURNER

the character of the flame at once alters. The air is now cut off and we get at the top of the tube the ordinary flame of a gas-jet. How different it is from what we had before ! Although there was a considerable amount of Carbon in the gas, yet the pale blue flame and the heat given out all pointed to one conclusion—consumption of the Carbon particles with the production of another product, a combination of Carbon and Oxygen—Carbon Dioxide.

This gas, which, as we have seen, is one of the constituents of atmospheric air, is also one of the products of the burning of a candle. If we place a candle inside a glass jar and replace the stopper, the flame will gradually die out. And if we rinse out the jar with a little clear lime-water

The Story of Flames

we shall prove the presence of Carbon Dioxide, for the lime-water will turn milky in colour. The little particles consist of Carbonate of Calcium formed by the union of the Lime with the Carbonic Acid given off by the candle flame.

We give a diagram (Fig. 34) representing the experiment. Another product of a flame such as that of a candle is water. If we carefully perform the previous experiment, taking care that the jar is quite cold, we shall notice that, as the candle flame gradually fades away, the sides of the vessel become dimmed and covered with a thin layer of

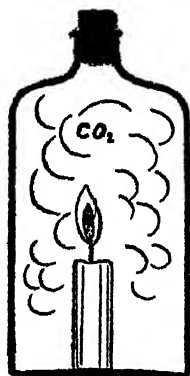


FIG. 34. CANDLE BURNING IN A JAR AND FORMING CARBON DIOXIDE



FIG. 35. A BLOWPIPE

moisture. It is water, and it is formed by the union of the Hydrogen present in the flame with the Oxygen in the air of the jar.

Let us now introduce some air into the flame of the Bunsen-burner by means of an instrument called a blowpipe. This consists of a tube (Fig. 35) with a smaller one attached to it at right angles, and furnished with a fine nozzle. If we direct the stream of air in the proper way, the flame becomes extended into a long jet which ends in a point (Fig. 36). The flame can now be roughly divided into two parts. The base B is very blue and it is known as the "Reducing" part of the burner. The part O extending

from the top of B to the extreme tip of the flame is the "Oxidizing" portion. It is very hot, especially at the extreme end.

If we introduce into the part B a little Oxide of Lead on a piece of charcoal, together with some Sodium Carbonate and heat it strongly, the Oxygen will be taken away from the Oxide with reduction to the metallic state. Little globules of Lead will be found on the charcoal. If, however, a piece of Copper be placed in the part O, it will become covered with a coat of Oxide, for it will unite in this part of the flame very readily with Oxygen. In chemical analysis

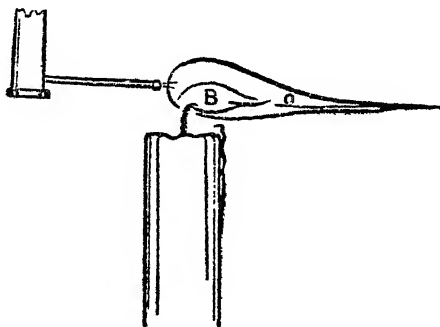


FIG. 36. EXTENSION OF A FLAME BY THE ACTION OF A BLOWPIPE

these two portions of the flame with their different properties play a very important part in the detection of substances. When any body unites with Oxygen or combines with it, we often get a considerable evolution of light and heat, and the body is consumed with the formation of fresh substances. A little piece of brown paper or a fragment of charcoal will illustrate this. When a match is applied to these substances they slowly smoulder away with a pale glow, giving off a little smoke and gaseous products such as Carbon Dioxide, etc. They combine with the Oxygen of the air just as we saw in the case of a candle flame, and give rise to the phenomenon of Combustion. It is true that the action is not very intense, but it is just as much combustion

The Story of Flames

in a small way as that which occurs on a larger scale in our grates. If we were to introduce the paper into a jar of Oxygen gas, that energetic supporter of all forms of combustion, it would be burnt up very completely in a few seconds.

When we poke an ordinary fire we illustrate these principles. The fire has been burning low, perhaps has almost gone out. The room is getting cold. We take up the poker and give the coals a good stirring up. Soon we notice a change. The dull lifeless embers begin to burn away afresh. A plentiful supply of air which they so much need—air full of life-giving Oxygen—percolates throughout the mass and into every hole and cranny. Little flames appear here and there. A pleasing warmth diffuses through the room. We have worked wonders with a piece of Iron. We have given the coals more Oxygen, and caused combustion to begin once more. Sometimes we augment the supply of air by means of the bellows. We direct a stream of air against the mass of heated coal and do not allow it to cool down again, but we keep on supplying it with more Oxygen. The most hopeless fire will often yield to such treatment. The homely bellows is often a veritable *deus ex machinâ* of an unpleasant situation.

As we have remarked before, it was Lavoisier who was the first to show what really happened when bodies were heated in the air, and the part played by Oxygen in combustion. He made clear the true nature of oxidation, and overthrowing the old notions which clustered around the "Phlogiston" theory, he proved that the phenomena attending combustion had their origin in the union of bodies with an active substance present in atmospheric air. When substances combine with Oxygen they do not always exhibit light and heat. If a bar of Iron rusts in the air, we do not notice anything very striking. But a bit of Iron wire if it be placed in a jar of pure Oxygen—what a difference! Just tip the end first with a fragment of burning Sulphur and then notice the evolution of light and heat which follows. At the end we can collect the product formed

by this striking union of the metal with the oxidizing gas. It is one of the Oxides of Iron. But we should have to wait some considerable time before we could collect a sufficient quantity of rust—another Oxide—from our bar of Iron. Here the oxidation takes place slowly. Quietly but surely the Oxygen of the air is doing its work of transformation. But there are no striking phenomena to witness. The oxidation which takes place in our bodies every minute of our lives, is a form of slow combustion with the liberation of energy from the burning up (as it were) of the organic compounds present. And the food we take is a source of potential energy, just as is the coal which we place in the fire-box of an engine. And as when the fire burns low we supply it with more coal, so, too, when we are tired and cold, if we are wise, we take in food (which, like coal, is full of Carbon) so that by its “combustion” we may maintain the heat of our bodies. By the process of respiration or breathing we take in the necessary supply of Oxygen for that purpose. And we are always supplying our bodies with the food and air which they need for the purpose of replacing the materials which are being burnt up (if we may so express it) within.

CHAPTER X

HYDROGEN AND ITS COMPOUNDS, SODIUM AND POTASSIUM

IF we were to exclude water from any estimation which we might make of the constituents of the world around us, we should remove at the same time a very important element, Hydrogen, which forms one-ninth of the weight of all the water upon the earth. So, too, in the bodies both of animals and human beings, amongst the many elements which combined together form all the complex substances found in their structure, Hydrogen, in company with Oxygen and Carbon, plays a very large part. Water, for instance, which is more abundant in the body than any other substance, is partly composed of Hydrogen, for in every molecule there are two atoms of the gas. And besides the inorganic constituents, there are all kinds of organic compounds such as fats, Carbo-hydrates or bodies consisting of Carbon, combined with Oxygen and Hydrogen, Sugar, Glucose and other bodies and albuminous substances made up largely of Hydrogen, together with Nitrogen, Sulphur, Carbon and Oxygen. In plants, also, Hydrogen enters into the composition of the organic part of their structure together with Carbon and, of course, other elements.

We may therefore say that Hydrogen is an element which is extremely widely distributed in compounds everywhere, though we cannot say that it exists in a free state to any great extent. And this obtains not only on our earth, for when we look at the heavenly bodies above us we know from what that wonderful instrument, the spectroscope, tells us, that Hydrogen is present in them also. The chromosphere of the Sun, for instance, that vast gaseous shell which

envelops it around, consists of glowing Hydrogen. And the red flames which are so prominent in the time of eclipse, in the light of modern research are compelled to give up the secret of their composition, for we know that they are composed of Hydrogen and Helium. In stars, also, and nebulae we find that Hydrogen enters into their composition.

There are a great many ways of making this interesting gas. Perhaps one of the most convenient ways of making it in small quantities, if we wish to learn something of its properties, is to take some acid which generally contains Hydrogen and then get some metal which will take its place. The gas thus released from its bonds will come off quite readily, and we can collect it for examination. Let us take Zinc as the replacing metal.

Into a bottle which is furnished preferably with two necks we put some granulated Zinc, that is to say, Zinc which has been melted and allowed to fall into a receptacle containing water, and on it we pour through the long tube (Fig. 37) some dilute Sulphuric Acid. At once the gas will commence to come off, and may be collected in jars of water by displacement. It is well to let a few bubbles escape into the air before collecting the Hydrogen so that it may be quite pure and free from any air. Since the gas is extremely light, and more than fourteen times lighter than atmospheric air, we can take away the jar when all the water has been displaced and, keeping it inverted, still retain the Hydrogen within.

If we apply a light to the mouth of the jar the gas will ignite with a pale blue flame which is very hot. But suppose that we take a small test-tube and fill it about half-full with the gas and then ignite it, we shall find that the Hydrogen mixed with air does not burn so quietly as before. It goes off with a loud pop—a miniature explosion.

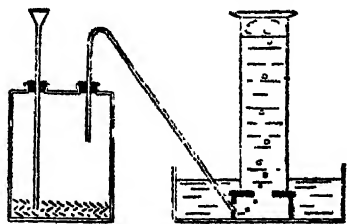


FIG. 37. PREPARING HYDROGEN FROM ZINC AND SULPHURIC ACID

108 Hydrogen & its Compounds

Hydrogen does not support combustion. It is a very different gas in that respect from Oxygen.

If a candle be plunged into a jar of the gas it will be extinguished, but the Hydrogen itself will take fire and quietly burn away. In doing this it combines with the Oxygen of the air, and the product of this combustion is water. From this fact Hydrogen derives its name—the producer of water (*hūdōr*, water; *gennaō*, to produce, Grk.). We can easily demonstrate this by holding a cold pane of glass (Fig. 38) over the flame of the gas. It will become covered with a fine layer of moisture which has condensed on the surface of the glass. But since most gases made in the ordinary way contain a little moisture which they carry over with them from the generating vessel, it is well to

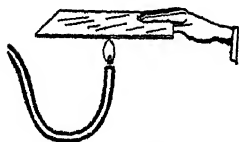


FIG. 38. CONDENSATION OF MOISTURE ON A COLD GLASS FROM A HYDROGEN FLAME

remove this moisture first. This is done by passing the gas, as in the figure, through a bent tube containing a substance called Calcium Chloride, which seizes upon the water present in the gas and greedily absorbs it.

Now it will be remembered that in speaking of Carbon Dioxide, one of the constituents of air, we drew attention to the fact that it is much heavier than air itself. Hence we were able to show that it could be poured out like water from one vessel into another. But in Hydrogen we have a gas which is diametrically opposite to Carbon Dioxide in this respect. It is so light that we can cause it to pass from one vessel to another by simple displacement of the air.

As will be seen from the diagram (Fig. 39) the receiving jar is held in an inverted position, and the one full of Hydrogen is carefully brought under it. There are other ways of illustrating the extreme lightness of this gas, such as the filling of soap-bubbles and balloons which immediately rise into the air. The application of this principle to the modern air-ship is well known.

If Hydrogen be taken as unity (1) we can compare the

densities of other gases in terms of it. Thus we may say that Oxygen is sixteen, and Nitrogen fourteen times heavier. In equal volumes of these gases, this would be the ratio of the weights, excluding decimals. A gas like Carbon Dioxide is twenty-two times heavier.

Now let us suppose that we have a jar full of Hydrogen in an inverted position and that we allow it to remain like this for some little time. If we examine it after the interval we shall find that a good deal of the gas has escaped into the surrounding air, notwithstanding the inverted position of the jar. It has diffused and escaped. Air has taken its place.

The phenomenon of the Diffusion of Gases, for most gases exhibit it, is rendered clearer by a consideration of what has been said previously concerning gases in general. We know that their molecules are ever in vibratory motion though the space which separates one of these tiny entities from another is incredibly small. And since the little particles of Hydrogen are so much lighter and have a greater velocity of movement than those of other heavier gases, we can understand that they gradually find their way out from the open jar. And it has been found that the rapidity with which a gas escapes is in proportion to its lightness.

Not only do gases escape from their containing vessels, but they also diffuse through one another. Even a heavy gas like Carbon Dioxide will pass gradually from one vessel to another if the two be connected. But as we might naturally suppose, the same volume of Carbon Dioxide would take longer to diffuse than that of Hydrogen. But gases diffuse not only through air but also through solids. If a tube open at both ends be provided with a stopper of paper, or better still, a thin sheet of charcoal (Fig. 40) and then filled with Hydrogen and immersed in a

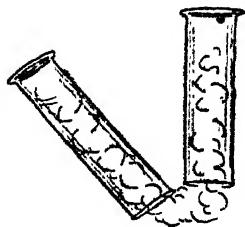


FIG. 39. ALLOWING HYDROGEN GAS TO PASS UPWARD FROM ONE JAR INTO ANOTHER

Hydrogen & its Compounds

vessel of water, after a time the gas will escape and the water will rise in the tube. But in a rough way we can always test the diffusion of gases by turning on a jet of gas in a room. Even if the atmosphere be kept perfectly still, it is surprising how quickly the unpleasant smell of the gas is noticed in the remotest part of the room.

If Hydrogen can pass with ease through various opaque bodies, we need not be surprised to learn that it will also pass into the inner structure of metals—be occluded, as it is called—and suffer absorption. Among the metals which

have this power, are Gold, Copper, Iron, Palladium. This latter absorbs nearly four hundred times its volume of the gas at the ordinary temperature of the air, and then gives it off slowly again. But the gas has altered properties now, and an increased chemical activity. If, as it is considered, the Hydrogen in this occluded state forms a kind of alloy with the metal, it is a very extraordinary one.

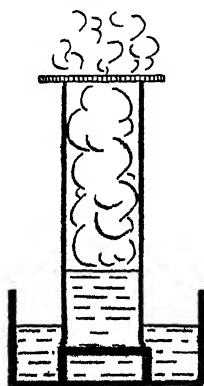


FIG. 40. DIFFUSION OF HYDROGEN THROUGH A CHAR-COAL SHEET

It has been advanced as another proof that the gas is closely allied to a metal. Indeed, it behaves more like a metal than any other element with which we are acquainted. In electrolysis, or the splitting up of a salt in solution, the metal is always found at the negative pole. This is the case with Hydrogen when water is split up, as it can be, by the electric current. Most acids are Salts of Hydrogen, and the Hydrogen can be replaced by a metal, as we saw at the beginning.

Water is the most important compound of Hydrogen and Oxygen that we know. It occurs everywhere in all states of purity. In Nature, in the human body, in plants, in our food ; everywhere we may say it is present.

In order that we may get pure water it is necessary to subject it to the process of Distillation. So many substances dissolve in it, it is so great a solvent for very many bodies

Hydrogen & its Compounds 111

that for chemical purposes in the laboratory a supply of absolutely pure water is necessary. In a small way we can effect the distillation by boiling some water in a flask or vessel of some kind and then condensing the vapour formed in a suitable receptacle. We give a diagram (Fig. 41) illustrating the process. From the containing vessel a long tube surrounded by a larger one passes down into a receiver for the liquid. And in order that the condensation may be complete, water is caused to circulate through the larger tube by means of connecting pipes. By this means the vapour as it comes off is at once cooled down and condensed, and the action goes on regularly and efficiently. Although the

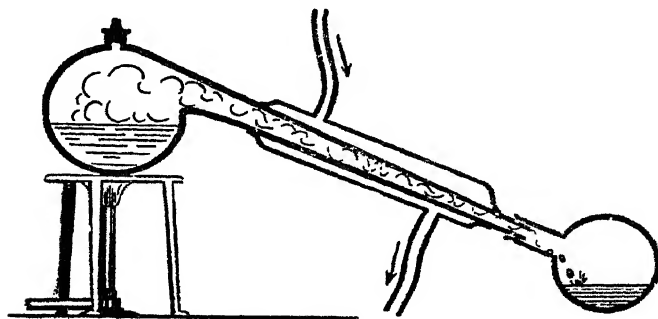


FIG. 41. DISTILLATION OF WATER

water thus obtained is pure and colourless, it is not so agreeable to drink as ordinary water which has come into contact with the air. As we might imagine, it is vapid to the taste and devoid of all life. It is most useful, however, in chemical work.

Water may also be rendered purer for many purposes by Filtration. If we cause it to pass through some substance such as filter paper, sand, gravel, etc. we thereby remove all the solid matter which the water often carries in suspension.

We have seen that in ancient days water was supposed to be one of the Elements just in the same way as Earth, Air and Fire. And it was not until the close of the eighteenth century that its compound character was definitely estab-

Hydrogen & its Compounds

lished by Cavendish. He found that water was really composed of two elements, Oxygen and Hydrogen, and that they united in the proportion of two volumes of Hydrogen to one of Oxygen.

Cavendish in his experiments made use of a strong glass vessel V (Fig. 42) fitted with a stop-cock S and two platinum terminals P, P, by means of which a charge of electricity could be passed into the interior of the jar, and so cause combination of the gases to occur. In another jar J the

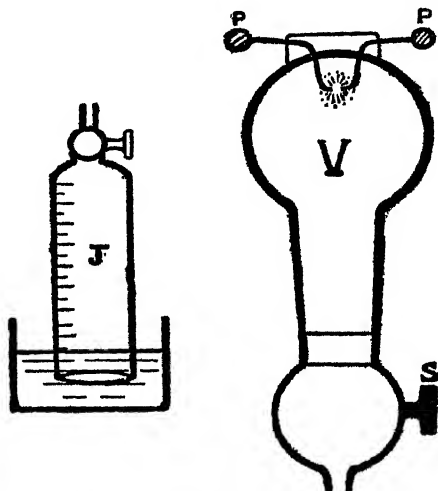


FIG. 42. CAVENDISH'S EXPERIMENT.

Oxygen and Hydrogen were mixed in their proper proportions. The two jars could be connected by screwing the one into the other. The vessel V was evacuated of air by a pump and then, when attached to J, the tap was turned and the gases filled the vessel and could be exploded. This was done repeatedly, and the jar J being graduated and standing in water he was able to note the proportion in which the liquid rose in this vessel when the gases were condensed in V. By this means Cavendish established the truth of his propositions. There was the water in the form of dew in V. Indeed, he collected quite a quantity. And

comparing the weight of this water with the weight of the gases originally taken, he found that it was identical.

A more accurate and refined method of carrying out the quantitative synthesis of water, or in other words to imitate the methods adopted by Cavendish more accurately, in forming water from Oxygen and Hydrogen and establishing the proportions in which the two gases unite, is by employing what is known as a Eudiometer (*eudios*, quiet air ; *metron*, a measure, Grk.). This consists of a long graduated tube (Fig. 43) fitted with platinum terminals at the top, which is closed. The lower end is immersed in Mercury, which also fills the whole tube. Hydrogen is passed up the tube, and its volume is then very carefully determined. Oxygen is next passed up. Its volume is estimated by taking the volume of the Hydrogen first passed up and then subtracting it from the total volume present in the tube of the gaseous mixture. The gases are now exploded by an electric spark through the platinum wires. At once the tube shows a deposition of dew on its sides, and the Mercury previously displaced rushes up the tube. The volume of the gas which remains is now carefully determined. It is Oxygen. If 100 volumes of Hydrogen be taken at the beginning we shall find that only 25 volumes of Oxygen remain behind at the conclusion of the experiment, supposing that we started with 75 volumes. Thus 50 volumes have been united with 100 volumes of Hydrogen, or 1 volume of Oxygen with 2 volumes of Hydrogen.

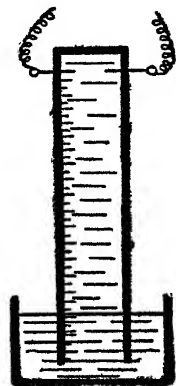


FIG. 43. EUDIO-
METER

Since the composition of water by weight has been established by numerous carefully conducted experiments with every degree of refinement and manipulative skill, it may be interesting to describe an experiment which we might make (roughly it is true) to illustrate the methods employed. Since the atomic weight of Oxygen is nearly 16,

114 Hydrogen & its Compounds

and from a knowledge of the actual proportions in which the constituent gases of water unite, the ratio of 12.2 would represent the proportions by weight of the gases in water. And this is what it works out at in the accurate determinations of to-day. Hydrogen is generated in a flask F (Fig. 44) and passes from thence into a curved tube A which contains Calcium Chloride. This frees the gas from most of its moisture. But this will be removed almost entirely by causing the gas to bubble through a second flask B containing Sulphuric Acid which, like Calcium Chloride, has an intense affinity for water. The gas then enters a vessel C which contains Copper Oxide, and which can be heated strongly

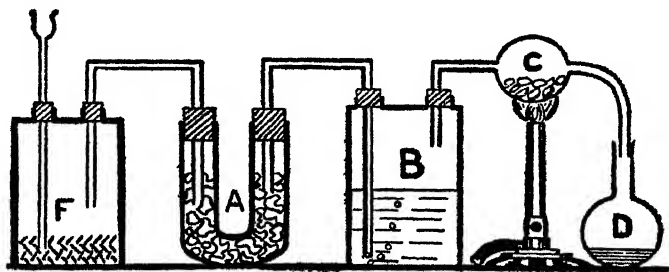


FIG. 44. APPARATUS FOR DETERMINING THE COMPOSITION OF WATER BY WEIGHT

by a gas-jet. Communication by a tube leads from C to D, another vessel in which the water formed by heating the Oxide with Hydrogen collects. As the experiment proceeds the Oxide loses weight, for its Oxygen has combined with the Hydrogen to form water. The loss represents the actual weight of Oxygen, and if we subtract this from the weight of water produced in D we shall obtain the weight of the Hydrogen which has entered into combination. The result of every carefully conducted experiment has been conclusive in establishing the ratio of about 16 to 2, or 8 to 1 as the true one. It is the proportion in which Oxygen and Hydrogen unite by weight to form water.

Pure water is colourless except in large quantities, when it appears green or bluish green. It freezes at 0° C.

Hydrogen & its Compounds 115

(32° F.) and boils at 100° C. (212° F.), under normal conditions.

There is another Oxide of Hydrogen besides water. It contains twice as much Oxygen. It is called Hydrogen Peroxide. To one part by weight of Hydrogen Gas there are sixteen parts by weight of Oxygen. It is a very unstable liquid and is always ready to give up half its Oxygen. It is very unlike water, although it is composed of the same elements. But the addition of an extra atom of Oxygen (as in the case of Ozone) makes all the difference. Like Ozone, it has very strong oxidizing powers. It bleaches colouring matter and turns hair to a golden-yellow. It may be prepared by treating Barium Dioxide with Hydrochloric Acid.

We have already mentioned in a previous chapter (Chap. VI) that in atmospheric air there is always present a small quantity of a compound of Hydrogen with Nitrogen called Ammonia. It is an interesting substance. When animal or vegetable matter decomposes we get Ammonia formed. It is also derived from horns, hence the old name of "Spirits of Hartshorn." Immense quantities are obtained by the after-treatment of the ammoniacal liquids in gas-works.

One of the best ways of preparing the gas is to heat Sal-ammoniac (Ammonium Chloride) with quick-lime.

Ammonia is very soluble in water and therefore cannot be collected in the ordinary way over water like Oxygen, but by upward displacement of the air in a jar (Fig. 45), for it is lighter than air.

Pure Ammonia is quite colourless, but possesses a strong penetrating smell. It is soluble in water to a great extent. One gram of water at 0° absorbs more than one thousand

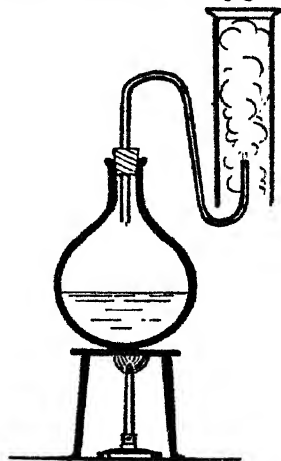


FIG. 45. COLLECTING AMMONIA GAS BY UPWARD DISPLACEMENT OF AIR

116 Hydrogen & its Compounds

times its volume of the gas. This solution constitutes the ordinary Ammonia of the shops. The gas is a non-supporter of combustion, and cannot be ignited readily. It burns more readily when a little Oxygen is mixed with it.

Ammonia forms different compounds or "Salts" when neutralised by acids such as Hydrochloric (forming Ammonium Chloride) or Nitric Acid (forming Ammonium Nitrate). These correspond closely to the compounds which are formed by the alkali-metals Sodium and Potassium. Thus we have Sodium Chloride and Potassium Nitrate. But in these compounds we have a definite metal, Sodium and Potassium, on which we can put our hands. In the Salts of Ammonia the Ammonium is merely a hypothetical substance which has not been isolated, and it is this "metal," if we may so call it, which forms compounds analogous to those of the metals Potassium and Sodium.

Potassium, a metal, belongs to what we may call a family group of closely allied members of what are called alkaline metals, whose Oxides form alkaline solutions which have the power of neutralising acids. Other members of the group are Sodium, Lithium, Cæsium, Rubidium, and that mysterious substance, the "Mystery Metal," Ammonium.

Potassium is very widely distributed everywhere in the soil, in plants, in the form of Nitrates (Saltpetre and Chili Saltpetre) and in many minerals.

In the early days of chemistry a substance like Potash, which is an alkaline compound of Potassium, was thought to be an element, and incapable of being decomposed into anything further. But by means of a strong electric current Sir Humphrey Davy proved that the real element in Potash was the metal Potassium.

Potassium, when freshly prepared, is a white silvery substance, quite soft, with a strong affinity for the Oxygen of the air. It is therefore generally kept in naphtha or some substance which is free from Oxygen. It decomposes water violently. If we put a piece on it, it will burn away, greedily absorbing the Oxygen, and producing so great a degree of heat by the combination that the Hydrogen of the water,

now set free, catches fire. The flame is tinged a beautiful violet—the characteristic colour of Potassium. When the action is over we get a solution of Caustic Potash left over. It is strongly alkaline.

The compounds of Potassium are, many of them, very important, and we shall look at some of them later on. We have made use of one Potassium Chlorate in making Oxygen Gas, it will be remembered, and there are others equally important.

Sodium occurs so much everywhere, and is so widely distributed, that its beautiful bright yellow lines which we shall study (together with others when we come to look at the spectroscope), are familiar objects to every student. And we know, moreover, that besides a host of other bodies, it is present in the spectrum of the sun, where it exists in the state of a glowing vapour. Stellar spectra reveal its presence, and in comets it can also be observed. In appearance and properties Sodium very closely resembles Potassium, though its action on water is not so violent. It forms many well-known compounds such as Common Salt, Sodium Chloride, Caustic Soda, Sodium Carbonate, an important constituent of soap, Glass and others.

CHAPTER XI

A CLOSELY RELATED FAMILY—CHLORINE, BROMINE, IODINE, FLUORINE

THE individual members of this group or family form compounds with other elements which closely resemble one another. For this reason they are generally classed under one head in order to exhibit more clearly their chemical relationship.

Chlorine does not occur in a free state in Nature but in combination with other elements, especially Sodium, forming vast deposits of salt in all parts of the world. And of course, in sea-water Sodium Chloride exists in large quantities; indeed, we may say that it is its chief constituent.

Since Chlorine exists in combination with Sodium in common salt, it would seem probable that we should be able to extract it from that body; and this is actually the case. In fact, in a general way, it is one of the best methods of preparing it. We take some salt and add to it a little black Oxide of Manganese and treat this mixture in a flask with Sulphuric Acid. Since the gas is very soluble in water, it is best to collect it in a jar by downward displacement of the air. It is nearly two and a half times as heavy as air, so that a jar can be easily filled with it.

Chlorine is a gas with a number of most interesting characteristics, though its irritating and very disagreeable smell renders its preparation undesirable except in a laboratory.

In our study of Oxygen we saw that it was a gas capable of great chemical activity, but for the most part we have to call in the aid of heat in order to cause the necessary

combination to occur. We then get spectacular effects, often of great beauty.

Chlorine, to a greater extent than Oxygen, combines very readily with a great many bodies, and that, too, at the ordinary temperature of the air, so that we obtain very striking effects of its activity. Take such a substance as Phosphorus; we know that it is a very inflammable body, and is always giving off fumes, the result of slow oxidation. But even Phosphorus does not spontaneously take fire in Oxygen gas, though it is always quietly "burning" away by a process of slow combustion whenever it is exposed to the open air. But with Chlorine its behaviour is very different. Here we get an immediate chemical action attended by light and heat. The Phosphorus ignites at once, forming the Trichloride, and although the brilliancy of the light is inferior to that in Oxygen, yet the greenish flame which we see tells us that the action is very intense.

Antimony in a fine powder also spontaneously ignites in the presence of Chlorine, or a very thin sheet of Copper will catch fire and burn in the same way.

Chlorine combines very energetically with Hydrogen. If we fill a jar with equal volumes of the two gases and expose it to the rays of the sun, the Chlorine will combine with the Hydrogen with explosive violence. Or the mixture of gases may be exploded by electricity. A vessel is fitted with two terminals (Fig. 46), P P, which can be connected up to an Induction Coil. When the current passes the gases combine at once. The vessel must be protected during the experiment. If we introduce a flame into a jar of the gas, the result in the light of what we have been saying is not difficult to forecast. If we make use of a candle, we know that one of the products of its combustion is Hydrogen, and of course

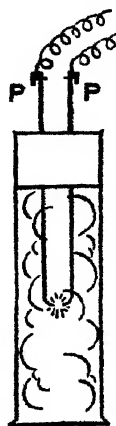


FIG. 46.
EXPLODING A MIX-
TURE OF CHLORINE
AND HYDROGEN BY
MEANS OF AN ELEC-
TRIC SPARK

A Closely Related Family

the Chlorine will immediately seize upon this. The consequence is that there will be a good deal of the Carbon in the flame which will be as it were left out in the cold altogether. It will be seen given off in the form of a thick smoky cloud. And a paper soaked with turpentine will actually take fire, so great is the heat of combination. Since in every molecule of the liquid there are at least ten Carbon atoms, it is not surprising that we get a very heavy deposition of soot in this experiment. Practical advantage is taken of the extreme ease with which Chlorine unites with Hydrogen. Chlorine itself is very soluble in water, which dissolves more than twice its volume of the gas. Now it has been observed that a solution of this gas gradually changes in colour (Chlorine in colour is yellow-green), pointing to some chemical action taking place in the liquid. What more natural than that some of the Chlorine should combine with the Hydrogen close at hand in the molecules of the water? But in the act of doing this a number of Oxygen atoms are necessarily left wandering about and ready to combine with anything. And in this state—this Nascent (*nascent*, am born, Lat.) state—they are capable of acting in a manner entirely different from ordinary atoms existing in a free state. This accounts for the loss in colour of the solution, and gives us the clue to the practical application of these curious facts. If we have present in the water any colouring matter of a vegetable substance, such as Indigo, for instance, the nascent Oxygen will quickly discharge the blue colour at the time when it is liberated.

It will be obvious, of course, that such a method of bleaching is not applicable to objects in a dry condition, since there would be no atoms of Oxygen ready to do their work in a nascent condition. Moisture is essential.

For bleaching purposes on commercial lines, Chlorine is generally used in a combined form with Calcium, forming what is known as Chloride of Lime, a mixture of Calcium Hypochlorite and Calcium Chloride. This substance is also used as a disinfectant and deodorant. On exposure to the air it slowly gives up Chlorine, together with an atom of

Hydrogen and Oxygen, forming what is called Hypochlorous Acid. This substance has strong oxidizing powers.

We have seen that Chlorine and Hydrogen unite together under the influence of the electric spark with explosive violence. And since it is not possible very well to examine the result of this combination under these conditions, we must allow the two gases to combine with one another more quietly. This we do by calling in diffused sunlight to our aid. Its radiations will do what the electric spark does, but without the destruction of the containing vessel. When the experiment is over, what is left? We know that when we caused Hydrogen to combine with Oxygen we obtained water as the product of the union of the two gases. But when we combine Hydrogen with Chlorine we get something quite different, an invisible, colourless gas with the power of giving out fumes, if the air be moist. It is Hydrochloric Acid, the only compound which Chlorine forms with Hydrogen. Equal volumes of the two gases must be taken if we are to prepare the acid in this synthetic (*sām*, together; *tithēmi*, put, place, Grk.) way. For the purpose of preparing sufficient quantities in order to study its properties, we can take some salt and treat it with Sulphuric Acid, replacing the Sodium in the salt with Hydrogen. Hydrochloric Acid as thus prepared is a colourless gas which fumes strongly in the air owing to its affinity for water. It is very soluble, therefore, as we might imagine, in water, which is able to dissolve more than four hundred and fifty times its volume of the gas. If we go into a shop and ask for some of the acid, this is what we get—a solution of the gas in water, generally a little coloured from impurities present. It is very strong and dissolves metals like Zinc, etc., with ease, the Hydrogen coming away, whilst the Chlorine unites with the metal to form a Chloride.

We can very strikingly demonstrate the composition of Hydrochloric Acid by volume, splitting it up into its constituent gases, and thereby showing that it is composed of equal volumes of Hydrogen and Chlorine.

A vessel V has two platinum plates P, P, connected to

A Closely Related Family

wires, W W, passing through a rubber cork. Two long tubes, T, T, are filled with the acid and inverted over the platinum plates. The vessel also contains acid. A current of electricity is now passed through the connecting wires. Little bubbles of gas are given off at each of the electrodes. Chlorine is evolved from the + pole, and we get Hydrogen given off at the - pole. After a time it will be found that equal volumes of the gases occupy the two tubes. One volume of Hydrogen combines with one volume of Chlorine to form two volumes of Hydrochloric Acid (Fig. 47). We have seen in our study, so far, of the properties of Chlorine and Hydrochloric Acid that one of their chief

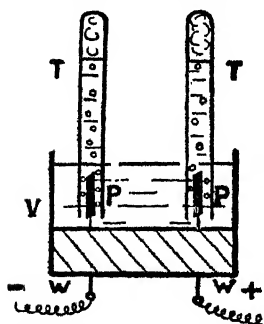


FIG. 47. DECOMPOSING HYDROCHLORIC ACID BY MEANS OF ELECTRICITY

characteristics is the ease with which both these gases (especially the latter) dissolve in water. And incidentally it reveals the remarkable solvent power of water. We know that salt, a solid, dissolves very readily, but by the simple substitution of Hydrogen for the Sodium we get a *gas* which is very soluble also. But there are degrees of solubility, and as we rise higher and higher in the scale, we notice how profoundly the character of the solution alters.

We have, for instance, seen that Carbon Dioxide dissolves in water to an appreciable extent, and under pressure to a greater degree, so that it renders the water bright, sparkling and buoyant. We enjoy drinking such water. When pure it is clear, tasteless and inodorous. It is also harmless.

Take now a gas like Ammonia. It is very much more soluble than Carbon Dioxide, but the solution is clear and bright, and the two solutions are scarcely distinguishable from one another by mere inspection. But directly we open a bottle of Ammonia as sold in the shops, which is a solution of the gas, the penetrating fumes and pungent smell warn us that here we have a liquid which, although it may be clear, is not tasteless and inodorous. Moreover, it is harmful.

Chlorine dissolves in water to form a solution also. But now a change occurs. The colour of the water when solution takes place is yellow-greenish in hue. It is evil-smelling, and clearly unfit for drinking purposes. The whole character of the water is altered. How much more so, then, in the case of Hydrochloric Acid, which we have just been studying! We get a solution which is not only very acid to the taste, but which has the power of dissolving metals, and fumes strongly in the air. What a contrast to the solution of Carbon Dioxide!

If we take a mixture of Hydrochloric and Nitric Acids, which of themselves are not able to dissolve such metals as platinum and gold, we can effect their dissolution very easily. Such a mixture is called "*Aqua Regia*," because of its action upon the so-called "*Noble*" metals. Hence its name (*aqua*, water; *regia*, noble, Lat.). The action which occurs is rather complicated, but it is interesting to observe that a great deal of Chlorine is given off in a nascent state. This no doubt plays a large part in the peculiar properties of the mixture. One part of Nitric Acid to three parts of the Hydrochloric are usually employed.

Potassium Chlorate with which, it may be remembered, we prepared Oxygen, is an important substance. It is formed by passing Chlorine into a warm solution of Caustic Potash. The Chlorate is not very soluble in water, and if we concentrate the resulting liquid by heat we shall get the salt to crystallize out in a fairly pure condition. The crystals are often large and in the form of flat six-sided plates. Since the Chlorate contains so much Oxygen it is extensively used in the manufacture of fire-works, and in making matches.

Chlorine, by reason of its suffocating and highly irritating effects on the human system, was one of the gases employed with such deadly results in the late war. A study of its properties tells us how applicable was its name of "*Poison Gas*."

Bromine is one of the few elements which we meet with in the liquid state. It is dark red in colour, and from its

A Closely Related Family

name (*Brōmos*, a smell, Grk.) we should naturally expect it to have a distinctive smell, which it decidedly has. It is soluble in water to a considerable extent, and the solution is often used because of its oxidizing action. In fact it imitates Chlorine in that respect, for it has a great affinity for Hydrogen, though not to the same extent.

It can be prepared by acting on Potassium Bromide with Sulphuric Acid in the presence of Manganese Dioxide.

We have seen that Chlorine forms one compound only—Hydrochloric Acid—with Hydrogen. So also Bromine. The compound is an acid like Hydrochloric, and it is known as Hydrobromic Acid. If we mix together Hydrogen and Bromine vapour we find that they do not unite together with the intense action which a mixture of Chlorine and Hydrogen gases displays. Even in direct sunlight we need not fear any explosive combination, which, as we have seen, occurs in the case of Chlorine. But what the sunlight radiations fail to effect, the magic power of the electric spark will at once perform.

Hydrobromic Acid, as we have said, closely resembles Hydrochloric Acid in its properties. It is very soluble in water, and fumes strongly in moist air.

In company with Hydrogen, Bromine forms a series of compounds—Bromic, Hydrobromous Acid and Perbromic Acid. And as we get Chlorides by the union of the gas Chlorine with a metal, such as Potassium, to form Potassium Chloride, so, too, in the case of Bromine we get Potassium Bromide, or any other Bromide corresponding to the metal which we may use.

Potassium Bromide is a very well-known substance. It is employed in medicine as a *sédative*, and in photography it has an action upon developers curiously resembling its physiological properties. If we treat Caustic Potash with Bromine we get Potassium Bromide formed in solution.

Bromine is prepared from sea-weed on the large scale, together with Iodine, the two processes going hand in hand. The "kelp" as it is called (the sea-weed after it has been burnt) is treated first with water and then with Sulphuric

Acid to decompose the sulphides, etc. The acid solution is now, after concentration, transferred to retorts or stills, and Manganese Dioxide is added and the Iodine condensed. After this process is concluded more Manganese is added and the Bromine is then liberated.

We have indicated the process by which Iodine is obtained from "kelp" or sea-weed, and we need not enlarge upon it further.

Hydriodic Acid with Manganese Dioxide and Sulphuric Acid give Manganese Sulphate, Water and Iodine. On a small scale in the laboratory Iodine may be prepared from one of the Iodides, such as Sodium or Potassium, by treating it with Manganese and Sulphuric Acid. The Iodine comes off as a beautiful violet vapour which condenses into a dark solid resembling graphite. The vapour is exceeding heavy, nearly nine times that of atmospheric air.

Iodine forms with starch a very beautiful and characteristic blue colour, which is used as an exceedingly delicate test of the presence of starch in any suspected substance. Now, just as in the case of Hydrochloric and Hydrobromic Acids we have Chlorine and Bromine attaching themselves to Hydrogen in the proportion of one volume of each of these bodies respectively to one of that gas, so also we find that Iodine and Hydrogen combine together to form an acid in the same proportions—Hydriodic Acid. It is a colourless gas, which fumes in the air and is very soluble in water. Iodine is largely used in medicine, as also are Potassium Iodide and others. It is interesting to note that the name given to this element is a Greek derivative, *ion*, violet, from the beautiful colour of its vapour.

We come now to the last of this remarkable family of the Halogens (Chap. xvii). We have seen that one is a gas (Chlorine), one a liquid (Bromine), one a solid (Iodine). Here we have another, which is a gas, Fluorine. Of all the members of the group, and indeed of all the elements, at ordinary temperatures, this gas is the most active, though, strange to say, it does not combine with Oxygen. It is widely distributed in combination with elements like Calcium,

A Closely Related Family

forming fluor-spar, with aluminium and silicon in the topaz and with others. Fluorine is univalent like the other members of the family. It forms with Hydrogen the acid called Hydrofluoric. If we treat fluor-spar with Sulphuric Acid we get the gas given off. But it must be observed that inasmuch as it attacks glass, gradually dissolving it, for it acts on the silica contained in it, we cannot prepare it in the usual way as in the case of other gases, but only in platinum or lead vessels. And this property is largely made use of for the purpose of etching various designs, graduated marks, etc., on all kinds of glass ware, scientific instruments and the like.

Suppose that we place in a glass jar a vessel of lead containing some fluor-spar and Sulphuric Acid (Fig. 48). We can illustrate the corrosive action of the gas by covering the jar with a pane of glass coated with wax except in those portions where we desire the fumes to act. After a time the figure corresponding to the bare parts of the glass will be permanently etched on the pane.

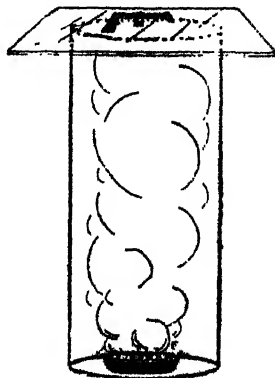


FIG. 48. ETCHING GLASS WITH HYDROFLUORIC ACID FUMES

CHAPTER XII

SULPHUR—PHOSPHORUS—ARSENIC—ANTIMONY— BISMUTH

MOST people are familiar with Sulphur, or Brimstone as it is called. Its familiar yellow colour and the irritating fumes which are produced when it burns are known to most of us. It has been found existing in a free state in Sicily and other countries, especially in volcanic districts.

Many metals in the form of sulphides contain Sulphur, such as Zinc Sulphide or Blende, as it is called, Copper Sulphide, and Sulphide of Lead. In the form of sulphates it exists in Gypsum or Calcium Sulphate, in heavy Spar or Barium Sulphate, and in Sodium Sulphate (Glauber's Salts). Some mineral waters, such as those of Aix-la-Chapelle, Harrogate, contain a good deal of Sulphur in the form of Sulphuretted Hydrogen, which we shall look at presently. To the presence of this gas they owe their unpleasant taste and smell.

In order to obtain Sulphur from its ores, it is usual to melt it down in a limited supply of air. The crude material thus treated is collected and subjected to distillation, and comes into the market either in the well-known form of "Flowers of Sulphur"—a very fine powder—or as "Roll Sulphur," which takes the shape of the original moulds in which, when melted, it has been cast. There is also a form of Sulphur which is known as "Milk of Sulphur." It has the appearance of a light powder.

Sulphur has some very curious characteristics when we come to study its nature. In the first place it is found to exist in three different forms or modifications. It is an allotropic substance. And it is the second element

which we have come across so far which exhibits this property.

In our review of the "air we breathe" (Chap. vi) we came across, it will be remembered, that curious gas called Ozone, which we found to be an allotropic modification of Oxygen, and as we go on we shall find that Phosphorus also exhibits the same power of existing in different forms. This is a very strange thing, for it leads one to suppose that there must be some inherent difference in the atomic and molecular structure of these bodies which accounts for their assuming different forms. At all events this is what appears to be the most likely explanation, and it is largely accepted to-day.

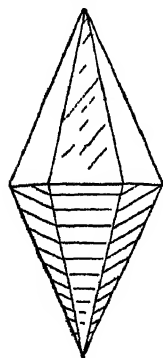


FIG. 49. CRYSTAL OF NATIVE SULPHUR

If we examine a piece of Sulphur as it is found in Nature we shall see that it is formed of a number of beautiful crystals which are octahedral (i.e. eight-sided) and belong to the rhombic system (Fig. 49). Crystalline bodies assume different forms as they pass from the liquid to the solid state, and it is possible to arrange them into systems corresponding to the particular shape and form of the little crystals of which their structure is composed.

Now, suppose that we take a little Sulphur and melt it in a flask and then allow it to cool down again. If we examine it carefully we shall see that it has crystallised now in quite a different way—long, transparent, needle-like crystals of prismatic form. They belong to an entirely different system, the Monoclinic (Fig. 50).

The curious thing about these monoclinic crystals obtained in this way is that they gradually pass into the octahedral form. Their structure, therefore, is far from stable. The third modification is seen on a consideration of the phenomena which Sulphur exhibits when it is heated to a temperature sufficient to cause it to pass into vapour.

At first it melts to a clear yellow fluid, but as it gets hotter

and hotter we notice that the colour of the liquid changes. It becomes much darker and thicker. But at a still higher temperature it again becomes fluid and finally passes off on boiling into a red vapour. Now when the Sulphur becomes fluid for the second time and is then poured into a vessel of cold water, we get a very curious modification (the third) consisting of a soft clinging mass of material which can be drawn out into long threads.

These are very extraordinary changes. Moreover, it is seen that whereas ordinary Sulphur is soluble in Carbon Disulphide, an evil-smelling substance which is able to dissolve so many substances, yet this peculiar modification, which reminds us of india-rubber, is insoluble. The Sulphur has been so changed by the molecular disarrangement it has suffered through the application of heat, that we can scarcely recognise it in its new guise. And it only emphasises the extraordinary properties which some bodies have of passing into different forms under the influence of heat, light or any other agency.

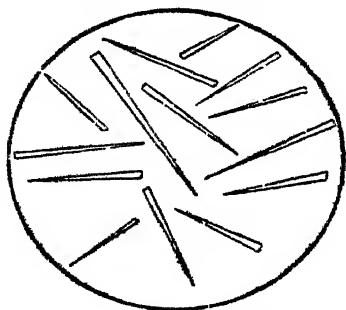


FIG. 50. CRYSTALS OF SULPHUR AFTER MELTING

Modern research tells us that there are bodies which change their colour under the stimulation of light-rays, and that when they are removed into the dark they quietly change back to their original colour once more. Moreover, it has been found that these changes can be brought about by the application of heat and cold.

Take Sulphur, whose properties we are now considering. It has been found that if it is subjected to the intense cold of solid Carbonic Acid, Sulphur loses its characteristic colour and becomes white ! But on being removed from its icy surroundings it gradually regains its original colour. Bodies there are, too, which exhibit these reversible colours on the application of heat.

Sulphur is very inflammable and burns away with a pale blue flame, uniting with the Oxygen of the air to form Sulphur Dioxide, a suffocating gas. It also exhibits great activity when metals like Copper are brought in contact with its vapour. Heat and light are evolved, and Sulphide of Copper is formed.

In order to prepare Sulphur Dioxide on a small scale for experimental purposes, it is usual to treat Copper with Sulphuric Acid. Copper and Sulphuric Acid give Copper Sulphate, Water and Sulphur Dioxide.

The gas is colourless and very soluble in water. It is therefore better to collect it by displacement of air.

Sulphur Dioxide has strong disinfectant and bleaching powers. Now, it will be remembered that Chlorine owes its bleaching power to the liberation of nascent Oxygen which, directly it is freed, seizes upon the colouring matter. Sulphur Dioxide bleaches in quite the opposite way. Instead of oxidizing, it de-oxidizes or reduces the colour of any silk, wool, etc., which may be exposed to its influence. What happens is that it liberates Hydrogen and takes away the Oxygen from the colouring matter to form Sulphuric Acid.

If we pass some of the gas into a jar which contains some flowers in a moistened condition, or a piece of coloured silk (Fig. 51), we can easily test its bleaching power.

The solution of the gas in water forms Sulphurous Acid. If we heat the solution it gives off the gas once more. Compounds known as Sulphites are formed when we neutralise the acid with a base such as Sodium Hydroxide or Caustic Soda.

When Sulphurous Acid is exposed to the air it absorbs an additional atom of Oxygen and is converted into Sulphuric Acid. This important acid will be considered in a later chapter (Chap. xiv).

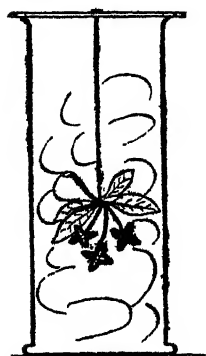


FIG. 51. BLEACHING A FLOWER WITH SULPHUR DIOXIDE GAS

Sulphur forms with Hydrogen a very important gas called Sulphuretted Hydrogen, or Hydrogen Sulphide. It occurs naturally in some mineral waters, and they doubtless owe their nauseous taste and smell to its presence, for it is soluble to a considerable degree. Many organic substances like eggs contain this gas when in a state of decomposition. This accounts for their proverbial odour. The tarnishing of silver in smoky towns is due also to this gas, which forms a thin film of black Sulphide of Silver on the surface of the article, showing that the atmosphere contains traces of this gas.

The interest of the gas in the laboratory arises from the use which is made of it in Analysis.

Suppose that we take some Copper Sulphate or "blue-stone," as it is popularly called, and having dissolved it in water, pass a stream of the gas through it. At once we notice a black precipitate formed of Copper Sulphide. If we take a solution of Antimony we get an orange precipitate. But if we take a solution of common salt and treat it in this way we get no precipitate, for Sodium Sulphide is a soluble substance. From this it can be seen that we can divide up metals into groups according to their behaviour towards Sulphuretted Hydrogen. And on obtaining any precipitate it is necessary, of course, to examine it, and to subject it to further tests. If there is no precipitate, it is clear that certain metals are absent from the filtrate, and we must apply other tests in order to isolate them. The whole subject is most interesting, but we are only able to indicate the barest outlines here.

Sulphur forms with Carbon an evil-smelling compound called Carbon Disulphide. It is a volatile inflammable liquid, and is an excellent solvent of many substances such as Rubber, Sulphur, Gums of different kinds, and other bodies. It is much used for this purpose.

Phosphorus, an important element which belongs to a group or family which includes Arsenic, Antimony and Bismuth, together with Nitrogen, whose properties we have already considered in our study of Air, is another of those

curious substances which exhibit allotropic modifications of great interest.

Phosphorus exists in two well-defined states with properties absolutely opposed to one another.

Yellow Phosphorus when absolutely pure is colourless or nearly so, and is an exceedingly inflammable substance of a wax-like appearance. It is always giving out fumes when exposed to the air, and since this is a form of combustion, but of course a very slow one, in a warm atmosphere oxidation may proceed so rapidly that the Phosphorus will eventually catch fire spontaneously, burning with dense fumes and forming the Pentoxide. In the dark the appearance of a stick of Phosphorus is very beautiful, since it is covered with a pale luminous glow which well justifies the name given to this curious element, the Light Bearer (*Phōs*, light; *pherō*, bear, Grk.). In a very finely divided state Phosphorus takes fire instantly, as can be seen by dissolving a little in Carbon Disulphide and allowing it to evaporate away on a piece of blotting paper. Oxidation occurs so rapidly that the whole takes fire. Since Phosphorus is so inflammable it is necessary to keep it under water, and to cut it also in that medium if a little piece is required for purposes of experiment. It is not soluble in water. It dissolves in olive oil to a slight extent if heated, and if the cork be removed from a bottle containing some of this solution the fumes become luminous and a pale luminous glow passes through the contents, which is sufficiently powerful to form a kind of lamp. We have drawn attention in our study of Oxygen to the vivid and startling appearance which Phosphorus exhibits when burning in a jar of pure Oxygen. If the vessel be examined after the action is over it will be seen to be covered with a light powdery substance, which very rapidly absorbs moisture from the air. This is Phosphorus Pentoxide, the element being united to five atoms of Oxygen. It is used as a drying agent when making gases on a small scale.

Now let us consider for a moment Red Phosphorus, as it is called, the allotropic modification of the ordinary or

yellow variety. What greater contrast in properties could we possibly imagine! Here we have a substance which does not fume when exposed to the air, is not inflammable, is not surrounded with that pale weird glow which is so marked a feature of the ordinary kind. It is not soluble in Carbon Disulphide, and is not poisonous like the yellow variety. It is difficult to believe, therefore, that we are dealing with the same substance. We have only to heat the red variety to a certain temperature, however, when it is at once converted into the yellow form. And conversely, if we leave this ordinary variety at a temperature of about 240° in some gas which cannot chemically act upon it, it becomes converted into the red form. And there are other ways of effecting the same object. Later on we shall come across further examples of elements which through some mysterious modification of structure conditioned by the relative position, so it is thought, of their atoms, exhibit striking anomalies. What is there in common, for instance, we might ask, between a diamond with its lustrous beauty and a fragment of soot which we can obtain from any ordinary candle? Yet both are forms of Carbon.

Phosphorus does not occur in the free state in Nature, but in the form of Phosphates, both in minerals such as Apatite and Phosphorite, which are largely composed of Phosphate of Lime. The crust of the earth consists in a great measure of Phosphate rocks, and the soil everywhere is full of Phosphorus in the combined form, and since it is soluble to a certain extent, plants obtain one of the chief essentials for their growth from this source. Indeed, the application of artificial manures which include Phosphates as one of their ingredients has to-day become quite universal. Phosphates of Ammonia, Lime, Potash, Superphosphates (a very useful manure), Basic Slag (which contains a large percentage of Lime Phosphate), and other Phosphatic compounds, are all largely employed both by the agriculturist and the gardener.

Nor must we forget those vast deposits of guano (now, alas, sadly depleted), so rich in plant food, by reason of its

valuable constituents of Phosphorus and other substances. And in the bones of animals there is also Phosphorus existing in the combined form of Calcium Phosphate. Thus it is that crushed bones in a state of fine division are used to-day as a form of artificial fertiliser by reason of their high Phosphorus content. And it is from bones that this important element may be obtained. If bones are burnt to an ash and the material treated with Sulphuric Acid, decomposition occurs, and the resulting Phosphate after being mixed with powdered Charcoal is distilled off in retorts and the crude Phosphorus afterwards purified.

Phosphorus forms with Hydrogen a curious gas, Phosphuretted Hydrogen, with a strong, unpleasant odour. The smell of decaying fish is probably due to its presence. It has the curious property of spontaneously catching fire when it comes in contact with air, giving rise to beautiful rings of smoke which behave as they rise into the air as if they were made of some elastic substance. These vortex-rings, as they are called, have the appearance of miniature whirlpools in the air with an internal motion (Fig. 53), as they can be made to pass through one another and to collide against each other (without breaking) and to exhibit other striking characteristics. The gas itself may be prepared by the action of Phosphorus on Caustic Potash.

That the spontaneous inflammability of Phosphine, as it is sometimes called, is due to minute traces of another substance, a compound of Hydrogen and Phosphorus, is seen by taking a small quantity of the gas and exposing it to light. Its inflammability vanishes.

Arsenic, an element which in some respects resembles a metal by reason of its lustre, etc., is found in Nature, combined for the most part with metals such as Cobalt, Nickel, Iron and Copper. Traces have also been found in certain mineral springs. That it should be included with Phosphorus in the same family is seen by its compounds which in union with Oxygen and Hydrogen resemble those of that element.

Arsenic is obtained from ores such as Arsenical Iron

pyrites by the process of roasting and condensation of the vapours thus formed in a large cool chamber.

When heated strongly Arsenic gives off a colourless vapour which has a smell resembling garlic. The Trioxide is generally obtained as a glass-like substance which forms with alkaline bases such as Potassium, Sodium, Hydroxides, certain salts called Arsenites, such as that of Sodium, for instance. The corresponding Salt of Copper is a pigment known as Scheele's Green. Emerald Green also is a compound of Arsenic, and Imperial Green. Both the Oxides and Arsenites are very poisonous. Since this is the case, it is not surprising that they have been used, together with other compounds, frequently for criminal purposes. And in many

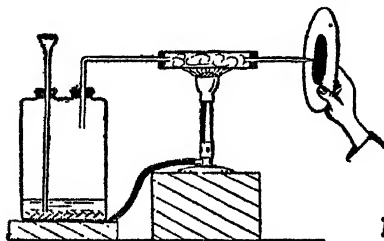


FIG. 52. DETECTION OF ARSENIC ON A PORCELAIN PLATE

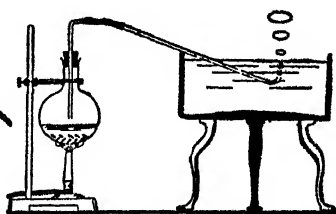


FIG. 53. SMOKE RINGS OF PHOSPHURETTED HYDROGEN

a *cause célèbre* they have figured with dramatic results. The tests for this element in suspected cases are many. One or two are indicated here.

It will be remembered in our study of Hydrogen gas that we made use of Zinc and Sulphuric Acid for the purpose of preparing that gas for examination. Now if we introduce into the flask containing these materials any solution containing Arsenic, the "nascent" Hydrogen at the moment of its liberation will combine with that element forming a compound called Arseniuretted Hydrogen. If this gas be heated it at once breaks up into Hydrogen and Arsenic. Accordingly the delivery tube from whence the gas issues is strongly heated (Fig. 52) and a perfectly clean porcelain plate is held in front of the tip of the flame.

A deposit of metallic Arsenic, like a dark mirror, is seen upon the plate. If necessary it can be dissolved in a suitable re-agent and verified.

Again, suppose that a solution is suspected of containing Arsenic. It is boiled with Hydrochloric Acid together with a small piece of perfectly clean, bright copper foil, when Arsenic will reveal itself in the form of a gray deposit. If this be dried and heated in a tube, a characteristic ring like a dark mirror will appear on the cold sides of the tube (Fig. 54). Other delicate tests involving much time and labour are used for the detection of this poisonous element. And the chemist is always on the winning side. The minutest quantity can be detected with ease.

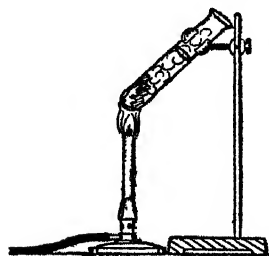


FIG. 54. DETECTION OF ARSENIC ON COPPER FOIL

Antimony is a metal which is generally found in Sulphur ore. It is somewhat like silver in appearance, brittle and easily broken up into powder. If heated very strongly it melts and burns with a white flame, giving off fumes of the Trioxide. But it does not appear to be affected if it is exposed to the air at the normal temperature. In a very finely divided state it takes fire spontaneously in contact with Chlorine-gas, with the formation of the Chloride. Antimony, like Arsenic, is exceedingly poisonous. But in most criminal cases where it has been used, its detection and separation have been successfully accomplished. Yet, like so many of these poisonous bodies, some of its compounds are used in medicine. There are also important alloys as Type-metal associated with it. One of the curious properties of Antimony is its power of forming not only acids but also bases with Oxygen and Hydrogen, whereas it will generally be found that metals are associated with Oxides of basic properties.

Bismuth is another member of the same family. It is a hard pinkish white metal which does not oxidize very freely. Some of its salts are used medicinally. It forms

with metals like Zinc, Lead and Tin curious alloys, whose fusing point is very low. A teaspoon consisting of this curious mixture of different metals will quickly melt away in a cup of hot water ! Since the respective melting-points of the component metals of this interesting alloy are very much higher even than boiling water, the combined effect is very peculiar. Fusible metal consisting of the same ingredients but in different proportions has also a melting-point below the boiling-point of water. It is used for taking casts from moulds of wood and similar substances.

CHAPTER XIII

ELECTROLYSIS, OR THE DECOMPOSITION OF LIQUIDS BY THE ELECTRIC CURRENT

IF we take a piece of ordinary Zinc and place it in a vessel of pure water we shall observe no action whatever. But if we add to the water a small quantity of Sulphuric Acid we notice a change at once. Little bubbles begin to come off from the surface of the Zinc, and the liquid is evidently being decomposed. If we collect some of the gas we shall find it to be Hydrogen. This reminds us very much of the way in which we actually made Hydrogen (Chap. x). The two experiments are closely related to one another. The liberation of Hydrogen results from the decomposition of the Sulphuric Acid.

Now in this particular instance the Zinc is dissolving away in the acid, but the energy due to this action is wasted. It is like coal with its store of potential energy burning away in a defective fire-box of an engine without accomplishing useful work.

In order to remedy this unsatisfactory state of affairs we add something else to the simple piece of Zinc in our glass cell, a Carbon plate with a terminal at the top to which we can affix a wire (Fig. 55). To the Zinc we also attach a wire, and joining up these two wires to a small electric-lamp as used in pocket batteries we get a distinct glow. An electric current is passing through the wires and the arrangement of Zinc and Carbon constitutes a simple voltaic cell. The terminals of the two plates are called the Poles, and the liquid is called the Electrolyte. The general name given to the action which goes on inside the cell is Electrolysis (*electron*, amber; *luō*, I loose, Grk.). It

signifies the splitting up or unloosening of the bonds which bind the atoms of the liquid together by the electric current.

The Carbon pole is $+$ and the Zinc pole is $-$, and the current flows from the positive to the negative pole and from thence through the liquid from the Zinc to the Carbon once more. The cell is a kind of furnace in which instead of coal we are consuming Zinc, and the chemical energy which is due to the reaction of the metal and the liquid is transformed into electrical energy, which by further conversion manifests itself in light and heat.

The difference of potential or power of doing a certain amount of electric work, between the positive and negative

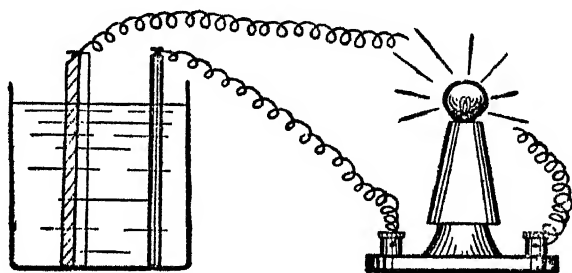


FIG. 55. VOLTAIC CELL AND LAMP

poles of our battery or cell, is known as the Electro-motive Force, and it is this which causes the current to flow through the circuit. And the action will go on until all the Zinc is consumed. The direction of the current is from the higher $(+)$ potential to the lower $(-)$.

From what we have learnt so far, it is clear that without chemical action of some sort we cannot obtain a current of electricity in a cell such as we have described. And the electro-motive force of this or of any other cell will depend upon the metals which we use. We shall see later that if we subject various metallic compounds in solution to Electrolysis we shall find that the metal always makes its appearance at the negative electrode. Metals are therefore styled Electro-positive, and non-metals which travel to the

Decomposition of Liquids

positive electrode are styled Electro-negative. A list of metals can be drawn up in the order of their action of oxidisability in Sulphuric Acid, and we find that Potassium heads the list followed by Sodium, Zinc, Iron, Hydrogen, Lead, Copper, Silver, Platinum, Carbon. And this electro-chemical action corresponds very closely to what is known as the "Contact-series of metals" drawn up by Volta, an Italian physicist, to express the difference in air of the electric potential between any two metals in the list. The further apart the metals are on the list above, the greater will be the electro-motive force if any two are chosen for the compounds of a cell. Thus Zinc and Copper will give a less electro-motive force than Zinc and Platinum, and Zinc and Carbon will be a still better combination.

The difference of potential in a cell or the electrical pressure (E.M.F.) is measured in volts. A volt is the unit. Different cells have different voltages. But when a current passes through wires which are called conductors and through the electrolyte itself, it meets with a certain resistance depending on the nature of the conducting wires and fluid. This resistance the current has to overcome. Metals on the whole are good conductors, silver and copper being the best. Water is a bad conductor, in fact almost an insulator in voltaic electricity. But directly we dissolve in it some salt, or add to it a little acid, we at once cause it to become a conductor of electricity. At the same time we must remember that, theoretically, a perfect conductor does not exist. Always there is a slight resistance which tends to obstruct the flow of an electric current.

The unit in terms of which the strength of the current is measured, is the ampère. Now, in the list we gave of the electro-positive metals there is seen Hydrogen, which is included among them. This is an extraordinary thing, and its bearing on the subject of voltaic electricity is very great. It behaves as if it were actually a metal. We shall see, later on, that with the metal in Electrolysis it travels to the negative electrode, and it has this further bearing on the voltaic cell in the following manner.

After a voltaic cell or battery has been working for some little time, we find that its output has considerably decreased. Its voltage drops and its current weakens through increased resistance. We say that the cell is Polarized. The chief cause of this phenomenon is the Hydrogen in the cell. Consider a plain cell of Zinc and Copper. When the circuit is completed bubbles of Hydrogen-gas are given off from the Copper plate, but gradually they form also a film or covering on the plate which then plays the rôle of a metal, being electro-positive, and as we see in the list of metals, occupying a place between Iron and Lead. We know how much higher Hydrogen is in the series than Oxygen, which is below

Carbon. The consequence is that the Hydrogen tends to send a back-current (Fig. 56) in opposition to the actual current in the cell because of the difference in potential between it and the Oxygen which is found at the Zinc plate. And this is a serious fault in all primary cells. Many endeavours have been made to counteract this curious behaviour of Hydrogen, a metal in this case, rather than a gas. We will mention two cells which overcome the difficulty in a practical way.

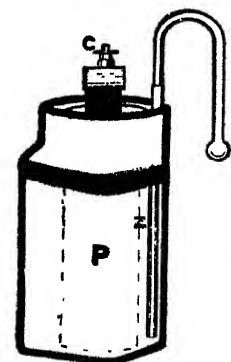


FIG. 57.
THE LECLANCHÉ CELL

The first which we will take is the Leclanché cell, so much used for ringing bells, etc. It consists of a porous pot P (Fig. 57) packed with Carbon and Manganese Dioxide. In the centre is a Carbon plate with a terminal C. Outside is a glass vessel containing a solution of Sal-ammoniac with a Zinc rod standing in it, Z. The products of the decomposition of the cell are Ammonia and Hydrogen, and the latter is oxidized by the Manganese which gives up some of its Oxygen for that purpose. For intermittent work this is an excellent cell.

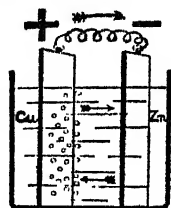


FIG. 56. VOLTAIC
CELL, SHOWING
THE EFFECTS OF
POLARISATION

Decomposition of Liquids

The second cell behaves in a different way. It is a Daniell cell (Fig. 58) and consists of an outer glass vessel, V, in which stands a porous pot. This contains a Zinc rod, Z, standing in dilute Sulphuric Acid. A Copper cylinder, C, is in the outer vessel and surrounds the porous pot. A saturated solution of Sulphate of Copper, with some extra crystals to keep up the strength of the cell, is in the outer vessel. The Hydrogen from the Zinc passes through the pores of the inner pot and, meeting with the Sulphate of Copper, displaces the metal with the formation of Sulphuric Acid, and the Copper is set free and is deposited on the Copper cylinder.

In both cells it is advisable to amalgamate the Zinc, that is to say, to cover it with a film of Mercury in order to prevent the rod from being decomposed and eaten away when the circuit is open.

We have seen that inside any primary or voltaic cell chemical action takes place with the production of an electric current, and we know that by reason of its energy this current can do work in various ways, work which manifests itself either in heat or light, in some magnetic effect and otherwise. We are all of us familiar with some of the forms which the conversion of this electrical energy may assume. The electric lamp in our rooms is an instance. But we are concerned at present with chemical phenomena, and we must endeavour to get some insight into the action of an electric current when we allow it to pass through liquids of different kinds, and thus do chemical work. For this will illustrate what we mean by Electrolysis. The current will decompose these liquids and the results are of great importance. Not all liquids are able to be decomposed. Pure water, for instance, oils of different kinds, and Mercury, which is a metallic liquid conducting electricity freely but refusing to be split asunder. But acids and acidulated water, chemical compounds of different kinds in solution, all these exhibit chemical change and decomposition.

If a jar of water be taken, acidulated with Sulphuric Acid, and two Copper wires immersed in it connected to a suitable

battery of two or three Daniell or other cells (Fig. 59), we shall observe the following phenomena.

Bubbles of gas will collect on the wire which is connected with the Zinc plate of the battery, and after a time will be given off freely and may be collected and examined. They will be found to be bubbles of Hydrogen gas. They are given off at the negative electrode ; what is happening at the other wire ? It remains in the liquid, quiet and apparently unaffected. But this is a fictitious appearance. We know that water is composed of Hydrogen and Oxygen, and we naturally expect to see corresponding bubbles of the

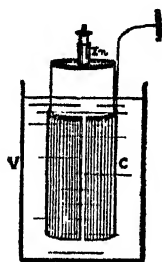


FIG. 58.
THE DANIELL
CELL

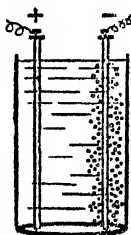


FIG. 59.
DECOMPOSITION OF
WATER WITH GAS
EVOLVED AT ONE
POLE ONLY

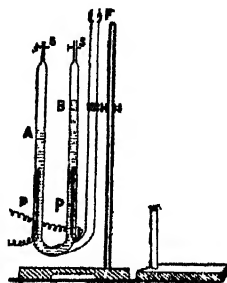


FIG. 60.
DECOMPOSING WATER
BY MEANS OF ELEC-
TRICITY

other element given off at the positive electrode. What has become of the Oxygen ? Take out the wire and examine it. Its colour has changed to a dark huc. The Oxygen was liberated, but at the moment of its freedom it combined with the Copper to form an Oxide, and consequently we see nothing of it. We cannot decompose water satisfactorily in this way. We must employ electrodes of some metal which itself is entirely unaffected, does not oxidize, and which gives off all the products of decomposition. Such a metal is Platinum.

Two graduated tubes A, B, connected to a funnel F are partly filled with acidulated water. At the bottom of each tube is a platinum plate P, P, connected by a wire to the

Decomposition of Liquids

outside. Each tube has a stop-cock, S S, at the top so that the products of decomposition may be examined. A suitable battery is connected up to the wires (Fig. 60).

When the current is allowed to traverse the electrolyte in the graduated tubes we notice that bubbles of gas are immediately given off this time, at both the electrodes. But a great deal more is given off from one plate than from the other—at the negative electrode. After a time it will be found that the volume of gas is double that of the other. Stop the action and examine the gases. The two volumes consist of Hydrogen. The single volume is Oxygen. One burns with a blue flame, the other causes a piece of smouldering wood to glow strongly. Water is composed, as we have already seen, of Hydrogen and Oxygen in the proportion of two volumes of the former to one of the latter (Chap. x), and if we subject it to electrolysis in the manner which we have described, we prove the truth of this statement, but in the opposite way.

We have used the term "electrode" several times. It is a Greek derivative (*electron*, amber; *hodos*, a way) and signifies the plates by which the current enters and leaves the electrolyte. The electrode by which the current enters is called the Anode (*ana*, up; *hodos*). It is the positive pole. The negative pole is called the Cathode (*kata*, down; *hodos*) and it is the electrode by which the current leaves the electrolyte.

Now Faraday styled the components or elements into which the electrolyte is broken up or decomposed "ions," and he further named the ion which appeared at the Cathode the Cathion, whilst that which appeared at the Anode he called the Anion. And the movement of the ions to their respective electrodes he called the "migration of the ions."

According to this, water, as we have just seen, when decomposed by the electric current, is split up into Hydrogen ions and Oxygen ions. Similarly Sulphuric Acid, according to this theory, is split up into Hydrogen ions and Sulphions. These latter at the anode combine with the water molecules, forming Sulphuric Acid and Oxygen which comes off at the

anode. Copper Sulphate is split up into Copper ions and Sulphions. The Copper is deposited on the cathode and the Sulphions behave as in the case of those resulting from the decomposition of Sulphuric Acid. So, too, if Hydrochloric Acid be subjected to Electrolysis, it would be split up into Hydrogen ions and Chlorions. The Hydrogen, behaving as a metal, would follow the current to the cathode, whilst Chlorine Gas would be given off at the anode. Common salt would suffer a like dissociation into Sodions and Chlorions. But in this case we should get no deposition of the metal since Sodium decomposes water, but we should get Hydrogen given off at the cathode. The amount of an element which is liberated is proportional to the strength of the current, and to the time during which it is flowing. This is Faraday's Law, and therefore it can be seen that we can use Electrolysis in order to measure the strength of a current. In the case of water it is known that a certain quantity of electricity (the ampère) will liberate a definite amount of Hydrogen and Oxygen. If the gases are collected together the total volume will amount to

0.1732 cubic centimetres. If a galvanometer be connected up to a voltameter (Fig. 61), consisting of a vessel filled with platinum electrodes and a graduated tube to collect the mixed gases, and a battery in series, we can measure the strength of the current by the amount of chemical action set up by it. The time is noted at the beginning of the action and also at the end. This with the volume of the gases which are liberated and the amount per ampère in one second will furnish the necessary data for measuring the current.

Now, in the Electrolysis of any liquid there is a certain minimum electro-motive force below which it is not possible to work. And for this reason. Suppose that we are decom-

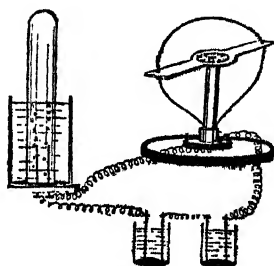


FIG. 61. MEASURING THE STRENGTH OF AN ELECTRIC CURRENT BY CHEMICAL ACTION

Decomposition of Liquids

posing water. The Oxygen and Hydrogen will try and unite with each other, and will set up a reverse electro-motive force in opposition to the actual electrolytic current. This opposing current is of the order of 1.5 volts (approx.), so that one Daniell cell giving about one volt is not sufficient, and we must employ at least two such cells if we wish to decompose water.

In the voltameter (Fig. 61) if, after the action has been going on for some time, we cut out the battery and connect up the wires to the galvanometer we can demonstrate this opposing current we have mentioned, for the needle will be deflected and in an opposite direction. The application

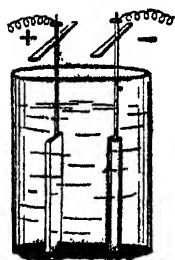


FIG. 62. ELECTRO-PLATING A PIECE OF IRON WITH COPPER

of Electrolysis to what is known as electroplating and the deposition of various metals for different purposes, is of great importance. From what we have seen of the action which goes on in a cell like that of the Daniell, we know that a metal can be deposited upon the cathode, and therefore, if we attach a suitable object to that electrode, gold or silver or any other metal can be deposited upon it in the form of a very fine coating or film by the aid of the electric current.

Suppose that we desire to coat a piece of Iron with Copper, we proceed as follows: We partially fill a vessel (Fig. 62) with a solution of Sulphate of Copper to which has been added a little Sulphuric Acid. From a support connected with the anode of a battery (+) we hang a plate of pure Copper. From another support a wire to which the piece of Iron is attached is joined up to the cathode (-). After a short time the Iron will be found to have received a coat of electrolytic Copper. If we want to Silver any article, the same procedure may be adopted, the anode being now a Silver plate, and the solution one of the double cyanide of Silver and Potassium.

It is possible also to coat a non-metallic substance with Silver, etc., if its surface be first of all rendered

conducting by means of a coating of blacklead or graphite.

We must now consider the modern way of regarding the phenomena of Electrolysis, for it is of great importance.

We have seen that water and other substances after decomposition appear as ions which migrate and wander towards each of the electrodes. According to the old idea, it was the electric current which split up the compound substance into these wandering particles.

To-day, according to the theory of Arrhenius, the celebrated Swedish chemist, the mere act of solution breaks down a body, such as common salt, into the ions of Sodium and Chlorion. All that the electric current does is to cause the positive ions of Sodium to be attracted to the cathode, whilst the negatively charged ions of Chlorine are attracted to the anode.

When water is decomposed, the liquid is dissociated into positive ions of Hydrogen and negative Hydroxyl ions consisting of one atom of Hydrogen and one atom of Oxygen joined together. When the current passes there is a rearrangement of these groups with a migration to the electrodes of the ions with their charges of electricity, the Hydrogen going to the cathode, as before, and the Oxygen to the anode.

Now, in Electrolysis, we find that the atoms of an element like Hydrogen carry one unit charge of electricity. The Chlorine atom also carries one atomic charge notwithstanding that its atom is $35\frac{1}{2}$ times heavier. The atom of Sodium is also associated with one unit charge. On the other hand the atom of Oxygen carries two atomic charges, whilst the atom of Tin carries four such charges of electricity. What is the meaning of this? How can we account for this anomalous behaviour? We have seen in a previous chapter (Chap. IV), when looking at the question of chemical combination, that the atoms of elements unite with one another with different powers. This is known as Valency (*valere*, to be worth, Lat.). And we saw that the atoms of different bodies such as Chlorine, Oxygen, Nitrogen and others

possess different powers of uniting with or holding in chemical combination the element Hydrogen. They are univalent, divalent and trivalent respectively. In the light of this we are led to believe that the unit charge which an atom carries in Electrolysis is very closely connected with the question of Valency, and that there is a parallel between the two. This explains, for instance, why it is that the atom of an element like Chlorine, whose atomic weight is 35.5, carries the same charge as the atom of Hydrogen. It is univalent. Oxygen is divalent and its atoms carry two atomic charges of negative electricity. And so on with the other elements.

From a study of the phenomena observed in Electrolysis it would appear that chemical combination and decomposition are connected with electrical phenomena, and that they are in some way electrical in nature. Let us go a step further. We know that ions or charged particles can be produced in a number of ways, by Radium, by the X-rays, by Ultra-violet light, and by other agencies. When produced their charge can be measured. The value corresponds approximately to that of the atom of Hydrogen in Electrolysis. The analogy is very extraordinary. And this is not all.

It has been found by a study of what are known as the cathode rays that these radiations consist of charged particles whose mass is about $\frac{1}{1836}$ of the mass of a Hydrogen atom. But their electric charge is the same. These infinitesimal particles are known as Electrons. The ions which we have observed in our study of Electrolysis are groups of atoms bound up with positive and negative charges of electricity, and the Electron is the ultimate or fundamental charge of every atom.

The modern theory of Electrolysis leads us into channels of thought which involve considerations of great interest at the present time. We have only been able very briefly to give some idea of what is involved if we look at Electrolysis in the light of modern research.

CHAPTER XIV

ACIDS—BASES—SALTS—CRYSTALS

It will be remembered that one of the methods by which we produced Hydrogen gas (Chap. x) was to take Zinc and treat it with dilute Sulphuric Acid. The metal gradually dissolves and ultimately forms a white substance called Zinc Sulphate. Now, all acids contain Hydrogen which can generally be replaced by a metal. And thus they are sometimes called "Salts of Hydrogen." This is their characteristic reaction.

In the early days of chemistry when men were groping in the dark, seeking light to illuminate facts which are familiar enough to-day, it was commonly held that all acids contained Oxygen. The very name supported the idea. It was the "producer of acid."

We do not hold this view in modern times. We do not consider that "empyrean air" is the active principle of acids. How can it be? There are acids such as Hydrochloric and others which contain no Oxygen. On the other hand, not every compound of which Hydrogen is one of the constituents, is an acid.

Acids generally mix freely with water. They turn blue Litmus (a vegetable dye obtained from certain lichens) in solution red. Hence they may be detected in minute quantities.

Not all acids contain the same number of Hydrogen atoms which are capable of being replaced.

Sulphuric Acid contains two atoms of Hydrogen. Nitric Acid only one. But Phosphoric Acid contains three replaceable atoms.

The most familiar acids with which we have to deal are

150 Acids—Bases—Salts—Crystals

Sulphuric, Hydrochloric, Nitric and Carbonic Acids. There are others, of course, some of which we have already noticed. There are also acids which occur naturally in the juice of fruits, such as Malic and Citric Acids. They give, no doubt, that refreshing flavour to fruit which is the result of their pleasing acidity. Now if we add to a solution of Litmus, which has been coloured red by an acid, a few drops of a solution of Caustic Soda or Potash, taking care not to add too much, we shall find that we can once more restore the Litmus to its original colour. We have added something which has neutralised the properties of the acid in the solution. Such a substance is called an Alkali, belonging to the class of bodies called Bases. These are metallic Oxides which when they unite with acids form a series of substances called "salts." Oxygen combines with nearly all of the elements to form compounds called Oxides. The oxides of the metals such as Caustic Potash are known as Basic Oxides, and it is they which have the property of neutralising acids. The non-metallic elements, on the other hand, form Oxides with acid properties—Acid Oxides in fact. On solution in water if only a portion of the Hydrogen in the water is caused to change places with the metal, we get what is called an Hydroxide. Thus Sodium forms the Hydroxide NaOH , and the remaining atom of Hydrogen is set free.

There are certain exceptions to the two classes of Oxides outlined above. Some elements like Chromium, for instance, form both basic and acid oxides. It is thought that the relative quantities of Oxygen which are present in these compounds may account for the difference observed.

If we take some Caustic Soda and very cautiously add to it, drop by drop, some Nitric Acid until the solution is perfectly neutral, i.e. when it neither changes red Litmus to blue, nor vice versa, and then evaporate off the solution thus obtained (Fig. 63), we shall get left behind a substance, Nitrate of Soda, which is a perfectly neutral body called a salt. This is one way of producing these substances. But there are other methods by which they may be prepared.

We can substitute a metal for the Hydrogen in an acid. Thus salt with Sulphuric Acid will give us Sodium Sulphate (Glauber's Salts). Iron treated with the same acid will give us green crystals of the salt Ferrous Sulphate.

Now, inasmuch as an acid like Sulphuric has two replaceable atoms of Hydrogen, we might expect it to form two different kinds of salts, corresponding to the replacement of all or part of the Hydrogen atoms. Thus, if a metal replaces all the atoms we get what is known as a Normal Salt. Thus Sulphuric Acid with Sodium will give us Sodium Sulphate, where both atoms of Hydrogen have been displaced. But in Sodium Hydrogen Sulphate, an Acid Salt as it is called, only



FIG. 63. FORMING CRYSTALLINE SALTS
FROM A SOLUTION BY EVAPORATION

one atom is exchanged for one atom of the univalent metal Sodium.

If we take an acid like Phosphoric, with three replaceable atoms, we can form three different kinds of salts and corresponding to the substitution of three, two and one atom of Hydrogen respectively.

Water, which is such a solvent, not only of some gases, as we have had occasion to observe, but also of solid substances, dissolves most salts in varying degrees. Thus common salt or washing soda, two well-known salts, dissolve very readily in water. But a substance like Calcium Carbonate is only slightly soluble. Sooner or later, the liquid will refuse, under normal conditions, to dissolve any more of a given salt. It is then said to be saturated.

152 Acids—Bases—Salts—Crystals

Now, hot water will dissolve more of a given salt than cold. A saturated solution, accordingly, if hot, will tend to deposit in the form of crystals some of the salt, as the temperature falls. But there are certain salts which still remain in solution after they have been dissolved to saturation, even when the temperature of the water has declined considerably. They form so-called super-saturated solutions. These, if kept quiet and undisturbed, will still remain in a liquid form. If, however, they are agitated, or if a very small portion of the original salt be dropped into the solution, the whole immediately crystallises out, and a considerable rise in temperature occurs. Sulphate of Soda or Glauber's Salts, and Acetate of Soda exhibit the phenomenon very well. And the heat given out is dependent on the following principles. If we employ heat to melt a body it does not become lost, nor can we indicate its presence by a thermometer. It is said to be Latent Heat (*latco*, be hid, Lat.). The number of units of heat required to melt 1 lb. of ice at 0° to water at 0° is 80. That is to say, there is sufficient heat in passing from the solid to the liquid state to raise the same weight of water through 80° C. And conversely when a body passes from the liquid to the solid state, a certain amount of heat is given out which in this case is able to affect a thermometer.

In the same way, if solids dissolve in water, a certain amount of heat is required in order to bring this about, and this heat is abstracted from the water in which we dissolve the substance. Thus if a very soluble salt such as Ammonium Nitrate be used the temperature will fall below freezing-point.

When salts crystallise out from solutions they are often found to contain a certain amount of water which is bound up in chemical combination with the crystals. We cannot exactly see this water, but it is present, nevertheless, in the crystals, and if we heat them it may be expelled. In such a case we speak of the crystals as containing "water of crystallisation." Not all crystals contain the same amount. Thus Hyposulphite of Soda, the well-known fixing salt used

in photography, contains five molecules and Sodium Sulphate ten, and so on. And the form in which salts crystallise often depends in some way upon the amount of water which they contain. The colour, too, will vary in the same way. Thus Cobalt Chloride, or indeed any of the salts of this metal, are pink in colour as long as they contain water of crystallisation—hydrated as it is called. But when they are heated they lose their water and become anhydrous (from two Greek words meaning without water) salts of a blue colour. All kinds of “sympathetic inks” are based on this principle.

Many salts when exposed to air absorb the moisture present and gradually become reduced to a moist or even liquid condition. Such bodies are called Deliquescent (*deliquesco*, to melt, Lat.). Different salts exhibit this property in varying degrees. Common salt, as every housewife knows, must be protected from the air or else it will become watery. Hyposulphite of Soda must be kept in well-stoppered bottles. But some salts are far more deliquescent.

Calcium Chloride, which is formed by treating lime with Hydrochloric Acid, eagerly absorbs moisture, and on this account it is used as a drying agent in chemical operations. We used it (Chap. x) in an experiment to determine the proportions in which Oxygen and Hydrogen unite by weight to form water.

We have seen that if we heat crystals which contain water of crystallisation they will give up this water. But there are some salts which do this quite naturally—by simple exposure to the air, in fact. Thus hydrated Carbonate of Soda, or washing soda, if exposed is liable to lose some of its water and to become white in appearance; so, too, Sulphate of Soda. They are, in fact, what is called Efflorescent bodies (*effloresco*, spring up, Lat.).

When bodies pass from the liquid to the solid state and assume the infinite variety of shape and form which we associate with the crystalline state of Matter, they introduce us into magic worlds where we get glimpses of beauty previously unexpected.

In the winter time when the weather is cold and frosty, or when snow is falling, we have most of us noticed the beautiful frost crystals on our windows, and have perhaps caught a snowflake lightly on our coat and examined the exquisite beauty and symmetry of the little crystals which make up the flake. We never seem to get to the end of these natural crystalline forms, which assume countless numbers of definite geometrical shapes. But they are so fleeting! They vanish so quickly! It is better to prepare them artificially if we propose making any serious study of crystalline shape and form. There are many natural bodies found in the

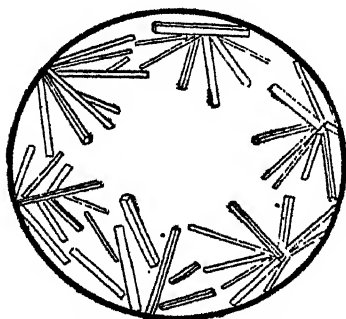


FIG. 64. CRYSTALS OF EPSOM SALTS

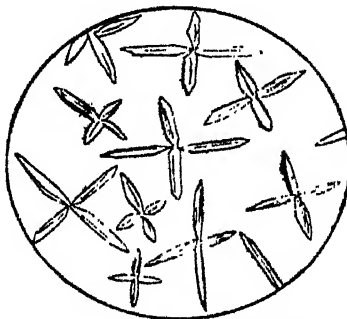


FIG. 65. CRYSTALS OF AMMONIUM CHLORIDE

earth's crust, such as Salt, Quartz, Natural Sulphur, the Diamond, Mica, Fluor-spar, etc., which may be investigated.

In order to obtain crystals in a simple way, it is sufficient to coat a strip of clean glass with a hot and saturated solution of the particular salt it is proposed to use. As the solution cools down the crystals will gradually appear, and may be examined by means of a small pocket lens, or by a microscope. They often present very beautiful forms. Common Salt assumes the appearance of little cubes. If Epsom Salts be taken the crystals will appear as four-sided prisms (Fig. 64) with flat ends. Sal-ammoniac exhibits some beautiful crosses and fern-like formations which are best seen under the microscope (Fig. 65). Potassium Bromide

illustrates the cross formation very well. Potassium Ferri-cyanide separates out in broad prismatic crystals (Fig. 66) which are deep red in colour.

One of the most striking forms of crystallisation is that exhibited by Nitrate of Silver (a compound of Nitric Acid and Silver) in conjunction with Copper. A drop of the Nitrate in solution is placed under the microscope on a slip of glass together with one or two fine Copper filings. A wonderful tree-like form of crystallisation takes place, which rapidly grows as you look at it under magnification. The growth resembles what has been called a "Silver Tree."

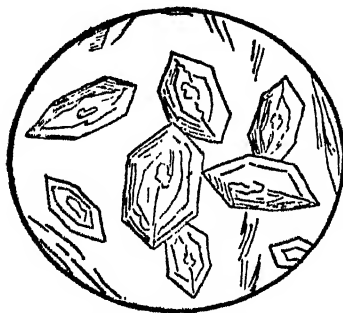


FIG. 66. CRYSTALS OF FERRI-CYANIDE OF POTASSIUM

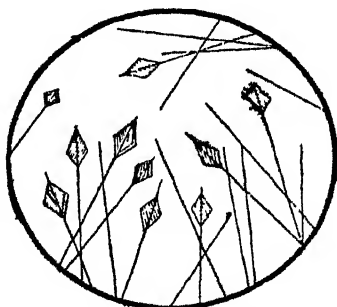


FIG. 67. CRYSTALS OF ANTIMONY TRIOXIDE

It is a purely chemical action which we witness. The Copper changes place with the Silver, with the formation of the Nitrate, and the original metal is deposited in the beautiful metallic state which we see.

Crystals vary much. Their structure is conformable to laws which embrace them within systems (7) of so-called "Crystal Architecture," but we meet with them in every form and shape. It would seem that every substance capable of crystallisation is capable of producing different results.

Sometimes crystals resemble one another very closely so that they appear, indeed, to be identical. Yet their chemical composition is not the same. This is the case

with the Phosphates of Potassium and Ammonium. We have seen that Sulphur assumes two different forms of crystallisation and is therefore known as Di-morphic (from the two Greek words : *dis*, twice ; *morphē*, form). And this also is the case with Antimony Trioxide, which can be obtained in the form of long crystalline needles of the rhombic form, and also in the cubic variety of the octohedron system (Fig. 67).

Some crystals exhibit different colours according to the direction in which the light passes through them. Acetate of Copper exhibits this phenomenon. The growth of crystals is the result of forces at work which give them the appearance of living objects. We know that they "grow," for crystals will assume quite big proportions if care be taken of them in their early state. And as a study of biology tells us that the plant or animal is made up of an infinite number of tiny cellular units consisting of that wonderful substance called protoplasm (the basis of life) and a nucleus, so it is known that crystal growth first starts from a nucleus, and proceeds by quiet orderly arrangement of the molecules to the final state. Thus they behave very much like living matter. Suppose that in course of formation a crystal gets broken. After a time, on careful observation, it will be found that it has repaired its damaged structure and proceeds on again as before.

Crystals are bounded by planes or surfaces which are known as "faces." And according to the arrangement of these planes as determined by law it is possible to foretell how any particular crystal will behave in its relation to light, electricity and the like.

With regard to light the behaviour is interesting. We know that the vibrations of the little particles in a wave are perpendicular to the direction in which the wave is advancing, just like a cork bobbing up and down on the surface of a pond. The wave goes on, but the cork remains. If the vibrations are limited to a single direction, instead of taking place in different planes at right angles or otherwise about the line of propagation, the light is said to have

poles or sides with different properties, to be polarised in fact.

Some crystals like Iceland Spar cause light to be polarised by splitting it up into two parts or sets of vibrations (Fig. 68). An object viewed through such a body appears to be doubled.

Many crystals under polarised light exhibit most gorgeous hues of colour—indeed, every variety of effect. Under the microscope not only can their growth be witnessed as it is displayed in endless forms, but we are introduced also into realms of colour sensation hitherto undreamt of

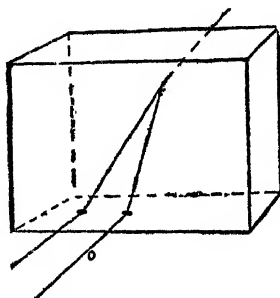


FIG. 68. RHOMB OF ICELAND SPAR
o, ordinary ray. e, extraordinary ray.
The black spots show the doubling effect.

under normal conditions. We may say that crystals are always attractive, always fascinating, but when colour is added—here, indeed, is a new world of great loveliness!

There are, also, crystals which are luminous and shine in the dark, especially after exposure to the sun's rays, the radiations of Radium and other agencies. The Diamond is one of these phosphorescent bodies. It has been known to emit the light which has been stored up as it were within its crystal structure after exposure to the electric spark, the rays of the sun and Radium. In this latter case it fluoresces brightly with pale green light which is very striking. Crystals of Fluor-spar, especially the variety called Chlorophane, are luminous when heated. Nitrate of

158 Acids—Bases—Salts—Crystals

Uranium emits a pale ghost-like glow spontaneously in the dark. If a number of little crystals of this salt be shaken together in the dark, each will emit a little flash of light, the result of friction.

Sometimes emission of light occurs at the moment when crystallisation takes place. This is seen in the case of Arsenious Acid, which emits a bright luminescence when a solution in Hydrochloric Acid is allowed to cool. Little crystals are deposited with bright scintillations as they form in the liquid.

Of late years an extensive use has been made of crystals in Wireless Telegraphy. There are some crystalline bodies which have the curious property of rectifying oscillatory currents and then passing them on as it were in one definite direction to the telephone receiver. The cause of their action is not very clear; it lies probably in their molecular structure.

The Fleming detector or valve much resembles them. In its original form it consisted of a Carbon filament lamp with a metal electrode sealed into the bulb on one side. If the negative pole of a battery be connected to the red-hot filament which has the property of emitting electrons, a unidirectional current will pass from the filament to the metal electrode of negative electricity, but not vice versa.

Some years ago certain substances were discovered which, curious to say, were capable of melting at two different temperatures—they had, in fact, a double melting-point. When subjected to heat they first passed into liquids turbid in appearance and resembling emulsions. But when further heated they became quite clear.

These turbid liquids were found to possess certain optical properties such as double refraction and interference phenomena (Chap. XIX), entitling them to be classed amongst solids of a crystalline structure. And so the term "liquid crystals" was applied to them. It was found by Lehmann that there are quite a number of these crystals which possess a liquid structure, and they possess some extraordinary characteristics by reason of it. Thus, they

collide with one another, and are capable of being squeezed or bent. When the pressure is removed they return to their normal shape. They are capable of uniting to form new individual crystals. As we have seen in ordinary crystals, these liquid structures have each a nucleus or "germ" which appears to be the starting-point of their growth. They raise the question as to whether crystals do not exhibit in some of their characteristics those actions which are generally associated with living organisms. They certainly exhibit some striking analogies when we compare them with such lowly forms of life as the amoeba, for instance (a microscopic animalcule perpetually changing its shape).

CHAPTER XV

SOME METALS AND THEIR PROPERTIES

THE metals play so important a part in our daily life, are so closely connected with every department of human endeavour and activity that it is necessary for us to consider some of the more important ones in detail and to examine their properties. The elements can be divided up into the two classes of metals and non-metals, and there is a great deal to be said in favour of this arrangement. It is true that there are elements like Arsenic which, though it is classed amongst the non-metallic bodies, yet in some respects resembles a metal. But on the whole the distinction holds good. So, too, is the distinction already noticed between the non-metallic elements and the acid oxides which they form with Oxygen, and the metals with their basic oxides (Chap. xiv).

There is no doubt that the metals are very sharply differentiated by reason of their general characteristics, both physical and chemical. For the most part they are solid lustrous bodies, very opaque and capable of being worked in various ways. They are good conductors of electricity and heat, and with acids they form salts by replacing the Hydrogen, whilst in electrolysis they are always to be found at the cathode, being electro-positive in character. These two distinctions are of great importance when any classification of the metals and non-metals is attempted. But the process of splitting up the elements into groups does not end by separation of the metallic from the non-metallic bodies. The metals are themselves capable of being grouped into classes in terms of the properties and general characteristics of the members which they

possess in common. And we shall look at the metals generally in this light.

The metals are irregularly distributed throughout the crust of the earth, and from the average composition of the Primary rocks we find that Iron in the form of Oxides, Magnesium, Calcium, Sodium and Potassium are the chief metals found in any quantity. The source of most of the metals is found in the deposits of ore which occur in so-called veins and lodes in rocks and rock-masses. These mineral deposits are largely composed of Oxides and Sulphides (Iron, Copper, Lead, etc.), whilst Carbonates are perhaps less common. The extraction of the various metals from these ores has led to the building up of a vast industry to-day, and we shall refer to some of the processes employed in the course of our survey. It is included in the science of what is known as Metallurgy.

The metals differ very much from one another in their general properties. Sodium, for instance, is a light, soft metal and will decompose water. Lithium is still lighter. Lead is a very heavy metal, generally of a dull colour. Although slightly soluble in water it does not decompose it. Gold is very nearly as heavy but it is more attractive in colour. Copper has a warm, pleasant look about it which establishes its identity. Aluminium is light and of agreeable hue. Mercury is liquid and stands by itself. Radium, by reason of its properties, has profoundly influenced modern scientific thought and research. Few are the eyes which have looked upon the metal itself. All form various compounds with the elements, such as Chlorides, Oxides, Nitrates, Bromides, Sulphides and others.

Of late years the curious property which some metals appear to possess of emitting a perceptible odour or smell has been the object of investigation. And it has been found that many metals such as Iron, Lead, Zinc and others emit a distinct and appreciable smell, which becomes more intense under the action of heat and friction. At a temperature of 100° it is quite noticeable. The curious thing about this phenomenon is that although on cooling

162 Some Metals & their Properties

down again the metal becomes almost inodorous, yet, after the lapse of some hours, the application of heat restores once more the emissive power.

The fact that a body like Iron requires some hours of rest before it again becomes odorous recalls another curious phenomenon—the “fatigue” of metals. We seem, many of us, to think, for instance, that a razor is all the better if it has a rest and is not used every day. And when we consider that a metal bar, if subjected to a series of stresses through bending or otherwise, becomes, without rest, less able to withstand the ordinary breaking stress, there seems no reason to doubt but that some deterioration does take place in the metal itself. Parts of an engine or of some machinery suddenly break down after having been subjected to stresses for a considerable length of time. And there would appear to be no safe limit, no “limiting stress,” as it is called. From a series of experiments in which the metals under stress were subjected to examination under the microscope, it would appear that the phenomenon of “fatigue” is due to minute molecular disintegrations which, when they are started, proceed onwards to complete tiring out, as it were, of the metal through minute tears in the structure, and so to ultimate failure. But a prolonged rest tends to put off the evil day—for a time at least. There does not seem to be any definite guarantee for the future.

Calcium is an element widely distributed in the form of limestone, chalk, marble. The actual metal itself is a white silvery substance which decomposes water like Sodium and Potassium. With Oxygen, Calcium forms Lime, which is obtained by heating the Carbonate in kilns.

Now, if we expose this substance to the air, or if we treat it with water just as we see labourers do in building operations, we get what is known as slaked lime. If we watch the proceedings, we shall see that a great deal of heat is given out as the result of the chemical energy, due to the combination of the lime with water. If we dissolve some of this lime in water, for it is slightly soluble, we get so-called lime-water.

If this water be exposed to the air it will quietly absorb Carbon Dioxide with the formation of the Carbonate, and the liquid will become cloudy. Hence we have a good test for the presence of Carbon Dioxide in the human breath, and incidentally prove one of the main facts of respiration. If we take a bottle partly filled with clear lime-water (Fig. 69) and furnished with two tubes, one, A, reaching to the bottom of the vessel, the other, B, considerably shorter, we can give the experimental proof in this way. If we inhale at B, bubbles of the outside air will pass up through the liquid which will, however, remain unchanged. But if we force air from the lungs through A, the liquid at once becomes cloudy through the deposit of Carbonate.

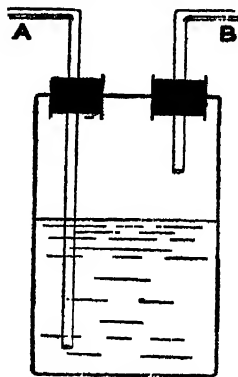


FIG. 69. DETECTION OF CARBON DIOXIDE IN THE BREATH BY LIME-WATER

Calcium Carbonate occurs naturally in enormous quantities in limestone regions. Here it often forms in caves those picturesque and interesting columns called Stalactites and Stalagmites. Water percolates through the roof of one of those fairy grottoes which, as at Cheddar, in Somerset, are famous for the beauty of their deposits, and dripping down leaves some of the Carbonate behind. This gradually grows into long stalactite "icicles" which hang down and meet the stalagmites rising up from the deposit on the floor of the cave. These caves are a veritable fairy-land when lighted up by electricity. The various formations scintillate with every hue and colour. Little lakelets reflect the columns and pillars, and tiny points of light give back the rays from the roof-mosaic, where countless diamonds, as it were, glitter and sparkle in the electric rays.

Sometimes from these limestone rocks water will issue, and, depositing on objects its charge of Carbonate, petrifies them with a crust of hard calcareous matter.

Lithium belongs to the group of Alkali metals of which

164 Some Metals & their Properties

Potassium and Sodium, two well-known members, have been already noticed. It is an exceedingly light metal, white in colour, and its salts are used in medicine. Many of its compounds have the property of imparting a magnificent red colour to flames, and if we examine them with a spectroscope we shall find the spectrum crossed by a characteristic bright red line which reveals the presence of the metal even in the minutest quantities (Fig. 70). This property of imparting colour to flames is shared by the other members of this group, as well as by Calcium and the other metals belonging to the group of the Alkaline Earths. It is not a common characteristic. The oxides of these metals are strongly alkaline.

Strontium and Barium, like Lithium, impart beautiful

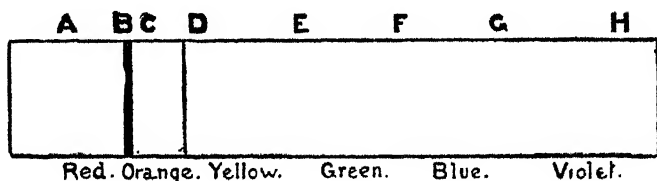


FIG. 70. SPECTRUM OF LITHIUM

colours to flames, the former a striking crimson, the latter a characteristic green. The compounds of these metals, and also Calcium with Sulphur, possess the interesting property of becoming phosphorescent after exposure to light.

Zinc is a metal extensively used for galvanizing Iron, or covering it with a thin layer of the metal. Aluminium is very light, does not tarnish or rust, and can be easily worked. Add to this its attractive appearance and lustre, and we can understand how popular it has become for all kinds of cooking and domestic articles. It forms with Magnesium an important alloy called Magnalium, which is largely used in aeroplane building by reasons of its lightness and great strength.

Copper forms some important alloys such as Bronze,

Some Metals & their Properties 165

which consists of Copper and Zinc with 3 per cent of Tin. Brass contains about two-thirds of Copper and one-third of Zinc. Gun-metal contains about 11 per cent of Tin, rising to 20 per cent and more in Bell-metal.

Lead is not a very attractive metal to look at, but it is an extremely useful one. One oxide is called Litharge, and another, Red Oxide or Red Lead. Then there is Sugar of Lead, or the acetate, and White Lead, the carbonate.

A great many people think that the use of Lead for water pipes is a source of danger in domestic supplies. As long as the water is not exposed to air or allowed to remain for any length of time in the pipes, it is not harmful. Soft water under extreme circumstances dissolves infinitesimal amounts of the metal. All water should be allowed to flow a minute or so before use.

Tin forms alloys called "Solders" in varying proportions with lead. It is also much used as a protective covering for iron in the tin-ware trade. Rolled into very thin sheets it forms Tin-foil.

Pure Gold is a very soft metal. It can be beaten into leaf so thin that it is capable of transmitting light of a green colour. An alloy with Copper forms the standard Gold coin of this country. It is also used for jewelry of all descriptions. The value of the gold present is expressed in terms of so-called "carats." Thus 18-carat Gold is a compound of 18 parts Gold with 6 parts of Copper. The alloy is harder and more durable than the pure metal.

Nickel is used in electro-plating and in alloys like German Silver, which consists of the metal associated with Copper and Zinc. Various foreign coins are made of this alloy.

In the extraction of Iron from its ores, which is accomplished by their reduction in a furnace (Fig. 71), under the influence of a blast of hot air blown through a pipe P, three

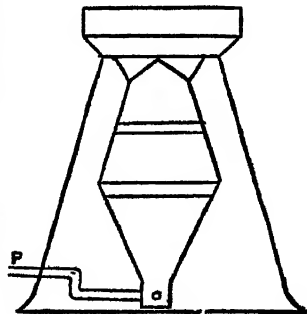


FIG. 71. A BLAST FURNACE

166 Some Metals & their Properties

distinct products are ultimately formed—Cast-iron, Wrought-iron and Steel.

The ore is mixed with coke and limestone or some other flux, and the molten mass is eventually drawn off at the bottom. This forms cast-iron. Wrought-iron is obtained by the process of "puddling." The impurities—Carbon, Sulphur, Phosphorus, etc.—are removed by melting cast-iron in a furnace with iron ore. Good wrought-iron contains very little Carbon and has a high melting-point.

Steel is manufactured largely by the Bessemer process. The finest contains less Carbon than that found in cast-iron. Its melting-point is higher, and it has an increased malleability. All the Silicon and Carbon in molten cast-iron is oxidized by a blast of air passed through it, and then a quantity of pure cast-iron is added in sufficient amount to convert the whole to steel by giving it a certain percentage of Carbon. Of later years the electric furnace has become a serious rival to the combustion type, not only for the purpose of reducing iron and the melting and refining of steel, but also for the production of such products as Carborundum Graphite, Silicon, Bisulphide of Carbon, Zinc, and those alloys like Ferro-manganese, Ferro-tungsten, etc., which are used in the manufacture of special forms of steel. In the production of cast- or pig-iron it has also been found that it can be made as cheaply as in the ordinary blast furnaces. In fact the product, containing as it does a very small percentage of Carbon, is a form of steel which can be refined and converted into pure steel quickly and at a less cost than by the ordinary methods of working. During the late war an increased use was made of the electric furnace for the melting of steel, and with excellent results. But this is not all. It has been found that Iron can be refined by electrolysis just like Gold, Copper and other metals, producing a metal of extreme purity and of great uniformity. For the production of high-class steel it seems well adapted.

The electrolytic process is extensively used for the refining of all kinds of crude metals. Copper, for instance, thus prepared, is of great purity. Gold, Silver, Tin, Zinc, etc., can

all be refined in this way. In many cases there are various by-products which help to reduce the cost of production, as in the case of Copper. In the production of Aluminium the electric current has revolutionized the whole industry.

Silver is, like Copper, an excellent conductor of heat and electricity. It easily tarnishes with the formation of the black sulphide. In coins it is usually alloyed with a little Copper to harden it. The nitrate is known as Lunar Caustic. It may be used as "marking ink." The Salts of Silver are much used in photography, in electro-plating and in other ways.

CHAPTER XVI

THE ROMANCE OF RADIUM AND RADIOACTIVITY

THE advance of Science during the present century has been extraordinarily great. Much of the knowledge which has been gained and many of the discoveries read more like a romance than sober facts. The story of Radium and the momentous conclusions drawn from it, if we consider nothing else, will undoubtedly render the last few years for ever memorable. They mark an epoch. With them there came into being an entirely new department of science and of scientific thought and expression. Into that crowded perspective of the past it is possible to look now with some measure of calm judgment, and to take stock of some of the great results revealed.

When Sir W. Crookes took the electric spark, which is a very beautiful thing in itself, and passed it through gases in highly exhausted tubes he obtained results which have led on to other startling discoveries. These have revolutionised modern scientific thought, causing new views to be held concerning the constitution of matter. Some of the results obtained were very curious and also very beautiful.

Crookes called the radiations emitted by the tubes the Cathode Rays, since they appeared to proceed from the negative electrodes. They caused the walls of the tubes to fluoresce and shine with a canary yellow or yellow-green light. Bodies exposed to the effects of this radiant shower shone out with various colours in the most bewitching way. A diamond glowed with a beautiful green colour, rubies displayed a rich crimson light, a common sea-shell surpassed all in the delicacy of its blue and pink hues. Mechanical effects were also produced. Little wheels on

rails spun round. The glass became hot under the bombardment of the rays. Even platinum was fused (Fig. 72) by converging the rays on to it by a mirror.

A magnet, M, caused the radiations to be deflected across the lines of the magnetic field (Fig. 73).

Crookes called the phenomena a discharge of "Radiant Matter," and held the view that they consisted of a stream of negatively charged particles shot out from the cathode with terrific velocity (up to 60,000 miles per sec.). Sir J. J. Thomson later determined the speed, the mass and the charge. This latter is identical with that of which the Hydrogen atom consists when an electric current passes through water in electrolysis (Chap. XIII). But the little particles themselves are nearly two thousand times smaller than any atoms of Hydrogen. Here we have something altogether contrary to our preconceived notions. The atom as generally understood is no longer the smallest entity. It is positively huge in

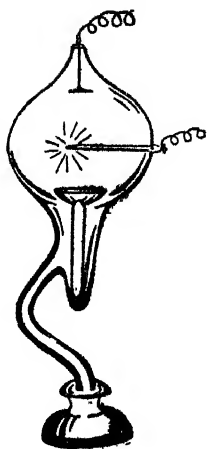


FIG. 72. FOCUSING OF CATHODE RAYS ON PLATINUM

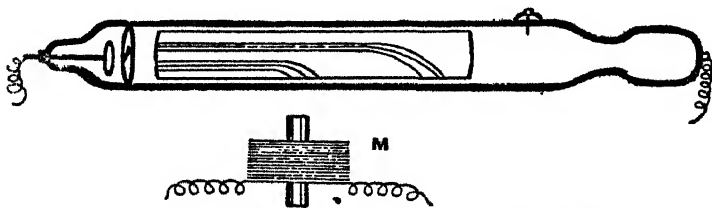


FIG. 73. DEVIATION OF THE CATHODE RAYS IN A MAGNETIC FIELD

comparison with that tiny negatively charged particle, the electron. Thomson has graphically expressed the corresponding relation, for he tells us that "the volume of a corpuscle (or electron) bears to that of the atom about the same relation as that of a speck

of dust to the volume of this room" (in which he was speaking).

The question was asked whether there were any other radiations, and also more particularly whether there were any bodies which spontaneously emitted rays capable of producing fluorescent effects. Professor Henry declared that he had found such a substance—the luminous Sulphide of Zinc. After exposure to the sun it emitted rays capable of traversing sheets of black paper and affecting a photographic plate. Then Becquerel found that the metal Uranium spontaneously gave out mysterious rays which traversed opaque objects and rendered the air a conductor of

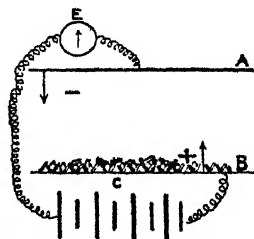


FIG. 74. EXAMINING A BODY FOR RADIO-ACTIVITY BY THE ELECTRICAL METHOD

electricity. And this, too, after having been kept in the dark for a considerable time. Then Crookes made the startling announcement that the Uranium itself was not responsible for these remarkable phenomena, but that they proceeded from some other substance—some hidden impurity, potent and subtle—within the metal itself. What was it? Did any other element possess this strange property? Who would answer the question?

At this point Mme. Curie took up the question. She exhaustively examined a large number of substances, and tested their power of emitting rays by their action on the air, i.e. rendering it a conductor of electricity, splitting it up very much in the same way as water is split up in electrolysis, into negative and positive ions. We say that the air is Ionized and the phenomenon is called Ionization. We can illustrate it in the following way :—

Two metal plates (Fig. 74), A and B, are placed one above the other with wires connecting them up to a battery C, and to an electrometer, E, to measure the strength of the current. At first there is no current passing since air is a non-conductor. But if a radioactive substance be placed on B, it will render the air a conductor, for it will be split

up into positive and negative ions capable of carrying electric charges. And the electrometer will be affected accordingly. A weak radioactive body, of course, will not influence it so much as one which can ionize the air more strongly.

Examined by this method not only Uranium but also its salts and minerals containing Uranium proved to be radioactive. And their activity was proportional to their uranium content. Pitch-blende (an ore of Uranium of a grayish or dark colour) proved to be about four times as active as Uranium, of which it only contains some 50 per cent. This was a striking discovery, for it pointed to the natural conclusion that hidden away inside there was some powerful subtle substance which was the chief cause of the effects observed. Mme. Curie commenced an exhaustive analytical examination of this substance, Pitch-blende, by chemical means. After much trouble and work she separated out a very active body associated with the bismuth of the Pitch-blende which she called Polonium, after her native country Poland. It proved to be very active. Later, after more arduous work, she succeeded together with her husband and M. Bémont in isolating a still more radioactive substance associated with the Barium portion, and she called it Radium.

It was the solitary remnant of many tons of Uranium ore, just a little white powder, the Chloride, insignificant in appearance, but its properties—these were to startle the world! From one ton of the Pitch-blende only a little speck of the Chloride was obtained! About 3·4 parts in 10,000,000 of the Uranium present, according to Rutherford.

The atomic weight (Chap. v) of Radium is 226·4. It belongs to the group of the alkaline earths comprised in Calcium, Strontium and Barium, and in the Periodic System of the elements it is included with them. Let us look at some of its properties.

The insignificant white powder by day seems quite ordinary, but at night time it seems to be transformed! It glows with a mysterious pale light, a phosphorescent

Romance of Radium

body ever luminous. A thousand years hence we know that it will be emitting the same quiet glow. Then, too, it continually gives out heat sufficient to melt its own weight of ice in one hour. Hence the salts of Radium, as Mme. Curie shows, are always at a temperature higher than their surroundings! This is a very extraordinary fact. Never before had the eyes of men beheld a substance which continually emitted both light and heat. A red-hot poker when removed from the fire cools down in time, its glowing light becomes less and less; soon it fades away altogether. In the fire-place it rests a dull, lifeless piece of iron. But Radium—it is always giving out heat, is always shining! How does it perform this apparent miracle? There appears to be no visible supply of energy from without. It is like a machine from which (if it were possible) we get more work than we put into it.

We know to-day the answer to this perplexing question. It is within the atom of Radium that we must seek for the source of that energy which is ever being poured forth. The atom is always breaking up and disintegrating, shooting off particles with fearful velocity, and displaying manifestations of colossal atomic energy in the form of light and heat. And with this breakdown of the atomic structure there arise, as we shall see, fresh products of transformation—new bodies which are themselves liable to change and to break up like Radium itself.

And if this be true of Radium and the other radioactive bodies, what stores of energy there are still untapped, locked up, imprisoned within the atoms of all material things! We must believe that there are "forces utterly disproportionate to the present sources of power," and that Radium is displaying enormous transformations of energy, which we might imagine to be the lot of any other kind of matter when the time comes for the discovery of utilising these hidden powers.

The ionization effects of Radium are very striking. It must be remembered that a very pure specimen of the Bromide or Chloride has an activity incomparably greater

than Uranium, which is generally taken as a standard. Yet salts much less active show the results very well. If we electrify a silk tassel (Fig. 75) and thus cause the threads to stand out apart, a tube of Radium brought near will cause them to collapse. The electricity has escaped. The air has been rendered a conductor.

Radium emits rays which pass through opaque bodies and affect photographic plates like X-rays. They are called the alpha, beta and gamma radiations, from the first three letters of the Greek alphabet. The first of these are positively charged particles, tiny projectiles shooting out from the atom with a velocity more than 10,000 miles per second, swifter by many thousand times than any flying bullet, and with an energy inconceivably greater. We need not wonder, then, that they can rend the air asunder, splitting the gases up into ions or little carriers of negative and positive electricity. And the number of these little projectiles—thousands of millions every second!



FIG. 75. IONIZATION EFFECTS OF RADIUM ON ELECTRIFIED SILK TASSEL

We have already mentioned in a previous chapter (Chap. VIII) that Helium is always associated with radioactive materials, and the very fact that its spectrum was obtained from the gas given out when Radium Bromide was dissolved in water led to the belief that the alpha particles are really Helium atoms. This has been definitely established. The elegant experiment by which Crookes demonstrated the visible effects of these little atoms on a phosphorescent screen in his instrument, the Spinthariscopes, tells us also that the little specks of twinkling light we see are the effects of individual atoms of Helium bombarding the luminous target, each with a definite impact of its own.

In a brass tube, T (Fig. 76), provided with a lens, L, a little needle, N, coated with Radium is fixed in front of a phosphorescent screen, Z. In a darkened room a peep into this little instrument reveals a wondrous sight. The starry heavens on the brightest and clearest frosty night do not

Romance of Radium

shine and twinkle more beautifully than the lovely scintillations—radiant specks of light—seen on the screen within! They flash and twinkle away in the most fascinating manner. Year in, year out, this gorgeous display goes on; and that with particles no bigger than atoms of Hydrogen. Yet, when we come

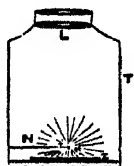


FIG. 76.
INTERIOR OF A
SPINTHARISCOPE

to look at the beta rays, we find that they are nearly two thousand times smaller still, tiny electrons shot out with the terrific velocity of more than 100,000 miles per second. The alpha particles, weight for weight, have many million times greater energy than a bullet from a rifle, but being comparatively large they are easily stopped by the thinnest material. But the electrons of Radium, by reason of their enormous velocity, have far greater energy, weight for weight, and plunge through a piece of wood or paper with ease. Expose a diamond so that it may be bombarded by this hurricane of particles, and it will shine with a beautiful light. And there are other bodies, too, which behave in a similar way.

Strutt has devised a remarkable instrument to demonstrate the charge of these beta rays. A glass tube, T (Fig. 77), containing a little Radium, R, is suspended inside a glass vessel, V, devoid of air. Two gold leaves, G G, hang from the lower end. Two tin-foil strips, F F, are placed so as to connect the inside of the vessel to earth by means of a platinum wire fused in the glass. A conducting film of phosphoric acid is placed on the outside of the tube.

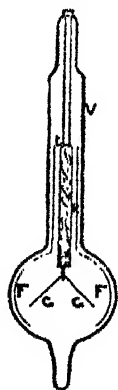


FIG. 77.
STRUTT'S
RADIIUM CLOCK

The beta rays charge up the gold leaves, which are repelled gradually until they touch the earth—connected strips of foil, when they at once collapse. But soon they begin to repel each other again, as the charge accumulates, and are then once more discharged. The action will con-

tinue as long as the Radium lasts. As its life is measured by thousands of years, this action is a very near approach to that oft-followed will-o'-the-wisp, Perpetual Motion. By timing the periodic movements of the leaves, a kind of Radium clock can be devised which apparently goes on for ever.

The gamma rays are similar to the Röntgen radiations. They are capable of passing through nearly three inches of solid lead, and are therefore of the most penetrating character.

Now, suppose we bring near a Radium salt some object such as a piece of card. After a time it will be found to exhibit strong radioactive properties. This is an extraordinary thing. It is known as "excited activity." How is it brought about?

Curie has shown that if some Radium be placed in an open vessel, V, under a glass jar (Fig. 78) with some pieces of cardboard, D B C, they will become radioactive. A thick plate of Lead, L, affords no screen. If the vessel containing the Radium be closed, there is no "induced" or excited activity.

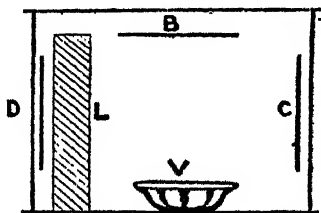


FIG. 78. INDUCED RADIOACTIVITY

We know to-day that the cause of this curious phenomenon is a substance of a gaseous nature as proved by the wonderful experiments of Ramsay and Soddy. It is, in fact, a gas—Niton—one of the rare constituents of the air. Rutherford has called it the Emanation. It is very active and renders, therefore, all bodies near it radioactive also. It can be liquefied and even solidified to a solid mass. It is very inert from a chemical point of view, and shares this property with those other rare gases like Argon which we have already noticed.

The emanation has but a transitory existence; its life is of short duration. In about four days its activity is reduced to one-half the initial amount; in a month it has

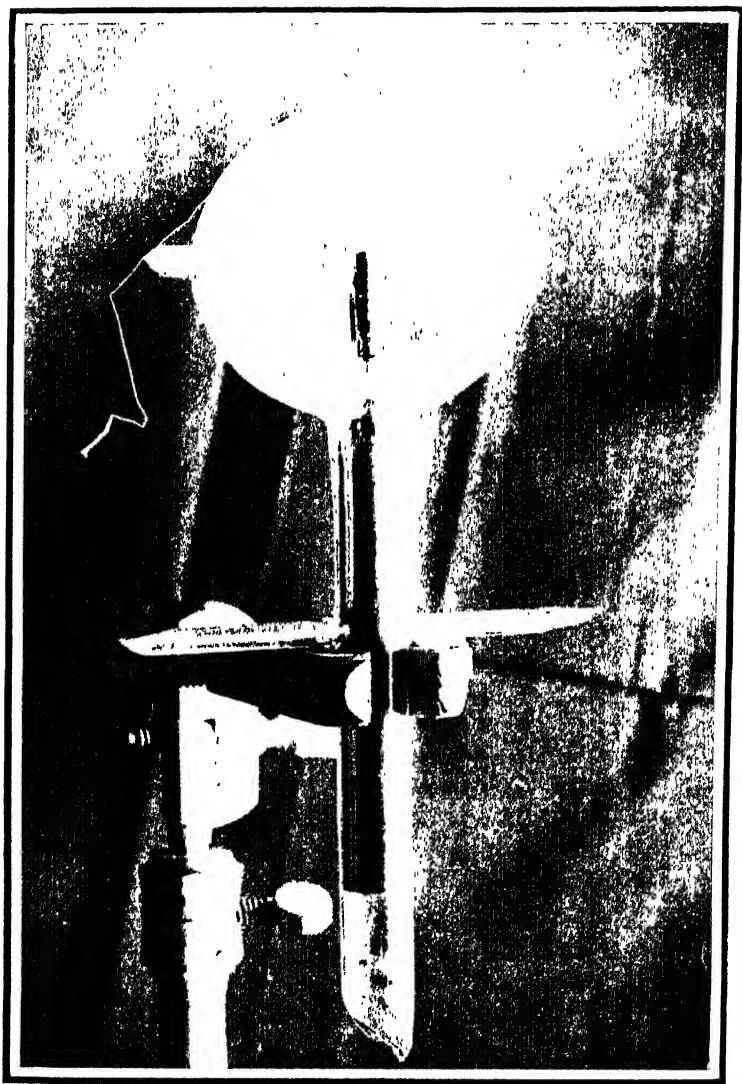
quite disappeared. But as fast as it disappears, a fresh amount springs from the Radium. We may say that in a given time, or indeed at any time, the balance between decay and production is always equal.

When it vanishes the emanation changes into a new substance, Helium. It is a transmutation of one element into another. The proof was furnished by Ramsay and Soddy who saw the spectrum of Helium stand out sharp and clear. Other investigators repeated the experiments. Ramsay and Gray weighed and measured the density of the emanation, working with a quantity of the gas less than $\frac{1}{10}$ of a cubic millimetre. This surprising feat was made possible by the use which they made of their micro-balance, which was capable of weighing a substance of the order of one-thousand-millionth of an ounce!

According to the Disintegration Theory of Rutherford and Soddy, the atom of Radium is always breaking up with the expulsion from an atomic system of negative electrons (which, like the planets of the Solar System, are ever oscillating around a central nucleus of positive electricity) of alpha particles carrying a positive charge. The Helium formed is the result of the loss of this charge. The energy stored up in the Radium atom is very great, the result of the disintegration ever taking place within it. If it were released suddenly it would produce a catastrophe of the greatest magnitude. There is a large amount of chemical energy in coal, although the method of converting it into heat is exceedingly wasteful. But the energy evolved in Radium is some million times greater, weight for weight.

The different products into which Radium and other bodies are transforming are many, and they are being continually produced. What we may consider for a moment is this: What is the beginning and end of them all? What is the origin of Radium and whence shall we seek it? The answer to these questions lies in the following considerations.

When we look at the wonderful bodies, products of the disintegration, we find that some have a duration of a few years, others three or four days, whilst the life of some is



James's Press Agency.

A SO-CALLED " PERPETUAL MOTION " MACHINE WORKED BY RADIUM.

Radium contained within a tube alternately charging and discharging a gold leaf through an earth-connected wire causes this movement to go on apparently for ever.

measured by minutes and even seconds. Compared with these short-lived substances we may say that Radium has a comparatively long life. Even in two thousand years its activity is only halved; and its sources seem still inexhaustible. It is still being continually produced. There must therefore be some other substance whose atom also breaks up and decays with the eventual production of Radium. Inasmuch as it is bodies of high atomic weight which are unstable, we must ask ourselves this further question. Are there any substances whose atomic weight is greater than that of Radium? And we answer that there are two, Uranium and Thorium, whose weights are respectively 238.2 and 232.4. Leaving Thorium out, for it does not concern us at the moment, let us consider Uranium in the light of our quest.

The activity of Uranium is not very high. Compared with a pure sample of Radium Bromide it appears insignificant. Still it is an active substance, and we must believe that it also suffers atomic disruption, giving out two alpha particles, and changing into a substance called Uranium X. It is always found in those minerals which yield Radium, yet the results of experiments undertaken were not very convincing. At least they proved that Radium was not the direct product. There appeared to be some other active body which eventually was isolated as Ionium, between; its atomic weight is 230.5. Since the atomic weight of the Helium (alpha) particle is four, and Uranium gives out two in changing to Uranium X, the new substance occupies the intermediate place very well, the order standing thus:—

Uranium (1), 238.5; Uranium (2), 234.5; Uranium X, 230.5; Ionium, 230.5, and Radium, 226.

It thus appears that Uranium is the true source of Radium, although it is difficult to prove it directly. It must be remembered that the average life of Uranium is calculated to be about 7500,000,000 years, and hence its rate of decay must be infinitely small. But with its feeble power it is just the very one needed to explain the presence of Radium in minerals. Whole geological epochs are needed for the

transmutation. We have them in the case of Uranium. And what about the final product of all those series of transformation substances? They read more like a romantic tale than the sober facts of science. What is the end of them all?

The answer to this momentous question is that we may reasonably expect the end-product to be some inactive substance which as far as we can tell is entirely stable. And since from Uranium downwards eight alpha particles are emitted, the last transformation product should have an atomic weight of $238.5 - 32$ or 206.5 . This corresponds very closely to that of Lead, which is 207.2 .

If this be the case, what an irony when we come to consider it! We know that the dream of the old-time alchemists was the transmutation of the base metals into perfect silver and perfect gold. To this end they toiled long and patiently. But their eyes never beheld the wonders of the radioactive bodies, nor did they imagine that hidden forces were working in secret to one great end. With our more perfect knowledge to-day, we know that Nature in her inexorable way sweeps all the wonders of Radium aside, and leaves us—Lead! It is her way of answering the wild dreams and aspirations of the old chemists.

Thorium is another substance which is radioactive. Since it is largely used in the manufacture of incandescent gas mantles, which contain about 99 per cent of the oxide, these lighting materials possess weird properties of affecting photographic plates and rendering the air a conductor of electricity. Some interesting experiments therefore can be carried out by unsuspected sources of radiation. Thorium emits a gaseous-like emanation like Radium and induces a temporary activity on surrounding objects. A product called Meso-thorium, with properties somewhat like those of Radium, is being produced on a commercial basis. It is hoped that it will act as a substitute for Radium, since its cost is very much less.

The question may not unnaturally arise whether radioactivity is confined only to a few special substances or is a

general property of all matter. It is a difficult question to answer. If there are other active elements which are breaking up and disintegrating, we must believe that the process is so slow, and the corresponding activity so weak, that as far as we can tell they appear to be inactive.

It is easy in the case of Radium to detect those wonderful phenomena of which we have been speaking, for its atoms are ever breaking up with explosive violence, but in the more stable elements—can we say the same of them?

Signs are not wanting that one or two elements like Potassium and Rubidium are radioactive, but in an infinitesimal degree. It is possible, too, that some of the others possess a slight activity, but the detection of it—that is the difficulty!

In conclusion, it is interesting to know that metallic Radium has been isolated by Mme. Curie in the form of a light coloured body which has a great affinity for water, like Potassium and Sodium.

CHAPTER XVII

HOW THE ELEMENTS ARE CLASSIFIED

THE reader of the foregoing pages who has now (perhaps for the first time) made his acquaintance with the chemical Elements may not unreasonably ask whether any arrangement and classification of them is possible. The same question was asked long ago, and for some time it was not found possible to answer it satisfactorily.

It must be remembered that there are more than eighty elements whose characteristics and properties are often widely different from one another. On the other hand, we often come across elements with properties closely related. The difficulty is to bring all those various bodies into some form of relationship to one another.

There are several ways in which we might make an attempt to solve this problem. We might divide up the elements into Metals and Non-metals, as is frequently done. The difference between them is very great. The former are for the most part heavy, opaque bodies, shining with metallic lustre and capable of being worked in various ways—drawn out or rolled, made into wire or sheet. They are solid at ordinary temperatures (with the exception of Mercury) and are good conductors of heat and electricity.

On the other hand, the Non-metals like Oxygen, Hydrogen, etc. are gaseous bodies, mostly transparent, and solid only under pressure and intense cold. They are bad conductors of heat and electricity. Solids like Sulphur, Phosphorus, Carbon, etc., are not capable of being worked like metals; they are not ductile and malleable.

This method of solving the problem is not wholly satis-

How the Elements are Classified 181

factory, since it involves the consideration of properties which are physical rather than chemical.

There is, however, one chief distinction between the two groups which we must look at in the light of chemical knowledge. It lies in the compounds which the members of each group form with Oxygen.

The Non-metals like Hydrogen, Nitrogen, Sulphur, Chlorine, Bromine, for instance, when they combine with Oxygen, form Oxides with acid properties strongly marked. Thus, Sulphur unites with Oxygen to form Sulphur Dioxide, and under certain conditions this combines with more Oxygen, forming the Trioxide. Both, when dissolved in water, form Sulphurous and Sulphuric Acids respectively. Carbon and Oxygen give Carbon Dioxide gas. The gas dissolves in water to a slight extent, forming a liquid with acid properties.

Now the Metals form Oxides with basic properties ; that is to say, they neutralise acids.

Potassium and water give Potassium Hydroxide a base, and Hydrogen. Sodium and water give Sodium Hydroxide and Hydrogen. Both Hydroxides form strongly alkaline solutions with water. Other metals like Calcium, Magnesium, etc., behave in the same way. And although there are one or two exceptions—a few Acid Oxides derived from metals—the distinction on the whole holds good.

It is possible to group some of the elements together by reason of their chemical relationship to one another ; and it can be seen that if such grouping could be extended and amplified we should be well on the road towards a systematic classification of the elements as a whole. There are four elements which are so closely related that it will be instructive to examine them in the light of what we have been saying.

These elements are Fluorine, Chlorine, Bromine and Iodine (*vide* Chap. XI). They are called the Halogens (*hals*, salt ; *gennaō*, produce, Grk.) because they all form compounds with the element Sodium, of which Salt is a Chloride. Thus, besides Sodium Chloride, we have Sodium Fluoride,

182 How the Elements are Classified

Sodium Bromide and Sodium Iodide. These compounds resemble one another very closely in their chemical properties.

Fluorine is the most energetic of them all, and exhibits the greatest chemical activity. Chlorine comes next, then Bromine, and Iodine. Thus we can arrange them in the order of their activities. Indeed, it is possible to compare the activities of all the elements in terms of one another. Now, in their power of combining with Oxygen we can also arrange them in gradational order. Fluorine does not combine with Oxygen at all. Chlorine forms very unstable compounds which break up easily into Chlorine and Oxygen. The Oxides of Bromine are more stable. Iodine forms very stable Oxides. The compounds which these elements form with Hydrogen are all univalent—only one atom of the gas is held bound.

A graduated series of these elements can also be formed in relation to their physical properties. Fluorine, for instance, boils at -187° , Chlorine at -35° , Bromine at 59° , Iodine at 184° . A similar series may be drawn up with reference to their melting-points. Even their colours show graduated tints from light (Fluorine, pale yellow) to very dark (Iodine). We may therefore say that members of this family exhibit very marked chemical and physical relationship to one another, and lead us to suppose that these elements are not independent forms of matter, but that they are bound to one another by some inherent property of atomic character.

There are other families into which the elements fall according to their chemical properties. All the members exhibit resemblances to one another. The Sulphur family consisting of Sulphur, Selenium and Tellurium, and the Potassium family consisting of Lithium, Sodium, Potassium, Rubidium and Cæsium are examples. It is evident, therefore, that we can allot certain groups of elements to certain divisions in our system of classification, though we cannot draw in this way any hard-and-fast line between the divisions. The system, so far, is not wide enough to embrace

How the Elements are Classified 183

all the groups and families which might be included. It is not sufficiently comprehensive for our purpose.

We must have a scheme at once wider and more scientific if we are to classify the elements in any co-ordinate and systematic way. We must gather up, as it were, all their resemblances and all their differences and then evolve some order and system on as satisfactory lines as possible.

In 1864 John Newlands described in the "Chemical News" what he called his "Law of Octaves." It was an attempt to solve the difficult problems which we have been considering by arranging the elements in terms of their atomic weights.

That there is a relation between the atomic weights of the elements and their properties is seen by looking at the members of the Halogen group which we have mentioned. Thus :—

Chlorine 35·45, Bromine 79·96, Iodine 126·85, show atomic weights of which that of Bromine is nearly the mean of those of the other two members of the group. The actual value is 81·15.

Also :—

Lithium 7·03, Sodium 23·05, Potassium 39·15, where the same relation holds good. The atomic weight of Sodium is nearly the mean of those of Lithium and Potassium. The value is 23·09.

Relations similar to these are met with in the elements everywhere. And Newlands pointed out that if a list were made of the elements arranged in order of their atomic weights, "every eighth member, like the octave of a musical note, would be in some respects a reproduction of the fore-runner." In a musical scale which represents a series of tones lying within a definite interval—the octave—if we start from any note like Middle C—the key-note—the interval of the octave is represented by seven definite tones giving a series of eight altogether, the last being the first (or key-note) of the octave above.

Now, in Newlands' time, Potassium, which happened to be the eighth of the series of known elements numerically above

184 How the Elements are Classified

Sodium, repeats more or less the general characteristics of this metal, both in its physical (colour, ductility, malleability, etc.) and chemical properties. So, too, its compounds. And so it was that the generalisation introduced by Newlands was styled the Law of Octaves. It met with little favour. Much ridicule and a cold douche of destructive criticism were the reward of Newlands' efforts. Then, as often happens, there appeared to be something in it, and some time afterwards the same fundamental idea was reproduced independently by Meyer and Mendelëeff. And inasmuch as similar elements appear to recur in successive periods, Newlands' arrangement of octaves was styled the "Periodic System of Arrangement." A reference to the table of elements representing this periodic classification will help the reader to understand more fully the system.

It will be observed that the elements are arranged in horizontal columns in order of their weights, increasing by a series of gradations. The elements in the same vertical column possess similar chemical properties. Sodium resembles Potassium, and Oxygen is like Sulphur. After the eighth element there is a repetition of the characteristics of the first series. Each vertical column, therefore, represents a family group of corresponding elements. The Halogen family stand out clearly in Group VII. And if we include all the elements in such a scheme as this, we shall have gone very far on our road towards a scientific classifying and arranging of them, not only in order of their atomic weights, but also in periodic or recurrent intervals of relationship.

Let us look at the scheme in detail.

In the first group (zero) we have the very rare gases which are found only in minute quantities in the atmosphere. They are Neon, Argon, Krypton and Xenon. Helium does not occur in the air, but is found in the sun's atmosphere, and is one of the disintegration products of Radium. These gases are non-valent—have no combining powers—they are extremely inactive substances.

In column I are seen the metals of the alkaline-earth family. These are univalent (power of uniting with one

How the Elements are Classified 185

other atom). They are Lithium, Sodium, Potassium, Rubidium and Cæsium, another well-known family, as we have before pointed out. Their Oxides form basic alkaline solutions and they all give rise to similar types of compounds. Copper, Silver and Gold are also included in this column as a sub-group, not only because they resemble one another, but because they are actually related to the metals of the alkaline-earths by certain compounds which they form.

In Group II are seen again members of the alkaline-earth family, this time di-valent (*duo*, two). They are Calcium, Strontium, Barium and Radium, with several others. In the same vertical column are Zinc, Cadmium and Mercury, a little family in a sub-group.

In Group III are tri-valent (*tria*, three) metals, of which Aluminium is very characteristic.

Group IV consists of quadrivalent elements (*quattuor*, four) such as Carbon, Silicon, Tin, and others less familiar.

Group V contains Nitrogen, Phosphorus, and others. Also a sub-group of Arsenic, Antimony and Bismuth. These are mostly tri-valent.

In Group VI we have such elements as Oxygen, Sulphur (both with marked resemblances to one another), and others. They are di-valent, also another sub-group.

In Group VII we recognise the Halogens, univalent. A well-known family.

In Group VIII we have some triplets, all closely related to each other.

It will be noticed that no mention is made of the element Hydrogen. It is not included in the scheme, since other elements have no corresponding properties to it. It is, thus, difficult to see where we can include it. It has the least weight (1.01) of all the elements, and is sometimes included in Group I. In Group III we have the beginning of a series of curious elements called the "Rare-Earths," with properties similar to one another.

It is difficult to assign to them any position in the table. They are put down in the order of their atomic weights, beginning at Column III. They are obtained from Monazite

186 How the Elements are Classified

Sand, and some of them, such as Cerium and Thorium (Oxides), are used in the manufacture of gas mantles.

Radium, it is interesting to note, with its atomic weight of 226.4, is included in Group II under Barium and Mercury. Thorium is in Group IV, and Uranium, with atomic weight of 239, is inserted under Polonium (atomic weight unknown) in Group VI with Chromium, Molybdenum and Tungsten. Niton, the emanation of Radium, is in the zero column. It has been shown by Rutherford and Soddy to be quite inert and without power of combination. It is therefore included in the non-valent family of the Argon group.

Speaking generally with reference to the scheme as a whole, we may say that the characteristics and properties of the various elements are expressed in terms of their atomic weights as they periodically occur—are, in fact, periodic functions of these weights.

If we form a mental picture of the properties of Sodium, for instance, in Group I, we see that as the atomic weight increases, these properties disappear. Aluminium is further removed from it, and Sulphur still more so, in characteristics. But the special properties of Sodium again reappear in Potassium, gradually to vanish once more until they are seen again in Rubidium and Cæsium. And so on. On the whole the scheme indicates a system of ordered relation and regularity for the elements in general. And if this be the case, it is not surprising that by the help of such a scheme it was possible for Mendelëeff to predict the presence in it of unknown elements. He was able to foretell their properties, still unknown, and assigned to them a definite place in the Periodic System.

Thus he predicted what he styled Eka-Boron, Eka-Aluminium and Eka-Silicon, since named Scandium, Gallium and Germanium by their discoverers. To-day there are gaps waiting to be filled which, as our knowledge increases, will no longer remain empty. Some element, perhaps, unknown on our earth, may fill them.

Some governing Principle appears to underlie the System, some Natural Law to govern it. And there are those who

How the Elements are Classified 187

believe that the relationships which exist between the elements suggest the connection of them all with some primary entity from which they have sprung. There are discrepancies in the classification, and the breaking up of the various families into sub-groups is objectionable, but on the whole the Periodic System has evolved order out of a chaotic mass of individual elements with many resemblances—and many differences—between them.

THE PERIODIC SYSTEM

O	I	II	III	IV	V	VI	VII	VIII
He 4.0	Li 6.94	Cl 35.5	B 10.8	C 12.005	N 14.01	O 16.0	F 19.0	
Ne 20.2	Na 23	Mg 24.32	Al 27.1	Si 28.3	P 31.04	S 32.06	Cl 35.46	
Ar 39.88	K 39.10 Cu 63.57	Ca 40.07 Zn 65.37	Sc 44.1 Ga 69.9	Ti 48.1 Ge 72.5	V 51.0 As 74.96	Cr 52 Se 79.2	Mn 54.93 Br 79.92	Fe 55.84 Ni 58.68 Co 58.97
Kr 83.8	Rb 85.45 Ag 107.88	Sr 87.62 Cd 112.40	Yt 88.7 In 114.80	Zr 90.6 Sn 118.7	Cb 93.5 Sb 120.2	Mo 96.0 Te 127.5	I 126.92	Ru 101.7 Rh 102.9 Pd 106.7
Xe 131.3	Cs 132.91	Ba 137.37	La 139.0	Ce 140.25	(Other Rare Earths) Ta 181.5 W 184.0			Os 190.9 Ir 193.1 Pt 195.2
	Au 197.2	Hg 200.6	Tl 204.0	Pb 207.2	Bi 208.0			
Nt 222.4		Ra 226		Th 232.4	U 238.2			

CHAPTER XVIII

THE WONDERS OF THE SPECTROSCOPE

THE light which strikes our eyes, whether from sun or distant stars, from a candle on our table or from the electric lamps in streets, consists of myriads of little waves traversing the "Ether of Space" with incredible speed. Not all the rays of light have the same wave-length, for some have a greater distance between one crest and another, or between one trough and another. And so we say that they are longer than others, although all are infinitely small. Thus, red rays from glowing sunset skies have a greater wave-length than the blue rays from the vault of heaven. And we explain all the wondrous phenomena of light and radiant heat and electric waves in terms of these oscillations in that wonderful medium, the ether, be they X-rays of less than 3-millionths of an inch in length, or light rays from 26 to 16-millionths, or electric waves which are very much longer, and which may be measured, some of them, in thousands of feet. But their velocity is ever the same, about 186,000 miles per second. And light, as it affects the retina of our eyes, comprises but a small part of all radiation. The human eye is restricted to a comparatively few wave-lengths. Our vision is limited. But what do we not owe to those waves of the visible spectrum which give us not only the light of day but all those wondrous colours which we see around us, the reds and greens and blues and violets and all the combinations of every hue and shade! And the colours of bodies are due to their "selective" action upon all the various rays which fall upon them, and which we know are combined in a ray of light. Thus the multi-coloured flowers in our gardens are absorbing some of the

190 The Wonders of the Spectroscope

little waves which fall upon them, while at the same time they reflect just those undulations which, according to their rate of oscillation or frequency, give us the sensation of blue, or red, or yellow, as the case may be. If a rose reflects all the different waves which strike it with little absorption, it will appear white to our eyes. If it absorbed every little wave and reflected none, it would appear absolutely black.

Let us now take a triangular piece of glass B A C (Fig. 79) representing a section of a prism at right angles to its axis and imagine, as Newton did in his historical experiments, that a ray of red light falls upon the prism at I. It will be refracted along I R, and emerging will again be refracted in

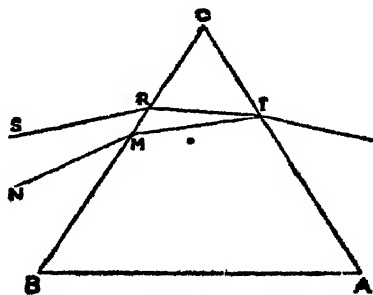


FIG. 79. REFRACTION OF LIGHT BY A PRISM

the direction R S. Falling as it does obliquely upon the face of the prism, the ray of red light is refracted or bent out of its course and caused to adopt a new direction.

In the light of this let us imagine that a ray of blue light falls upon the prism also at I. It is refracted just like the red ray but with this difference, that its deviation from its original source is greater than in the case of the red ray. It will be refracted along I M, and on emergence will be further bent in the direction M N. This is what is called the refraction of light. We have in this simple way turned and bent it out of its course. And we see, moreover, that blue light suffers greater refraction than red.

Again, let us imagine a ray of light passing through a

The Wonders of the Spectroscope 191

slit S (Fig. 80) and falling upon a prism. The light will be bent out of its course as before, and if received on a screen, N, will reveal itself in the form of a beautiful coloured band. All the colours of the rainbow will be there, ranging from red through orange, yellow, green, blue, indigo and violet. As before, the most refrangible rays are the blue and violet, while the least refrangible will be the red rays. This beautiful experiment introduces us to what is called the Spectrum, and the spreading out of the rays each in their order of refrangibility is known as Dispersion. The spectrum really consists of different images of the slit lying next to

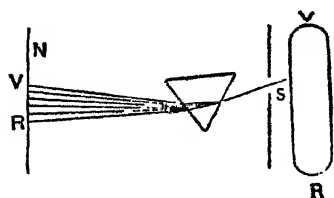


FIG. 80. FORMATION OF THE SPECTRUM



FIG. 81. EFFECT OF INTERPOSING A SECOND PRISM IN THE PATH OF THE REFRACTED RAY



FIG. 82. FORMATION OF WHITE LIGHT BY RECOMBINATION OF COLOURS

each other side by side according as the glass disperses the various colours.

Newton now tried an interesting experiment. He had produced his spectrum, roughly it is true, and he wished to see what would be the effect of interposing a second prism in the path of the refracted ray. The first spectrum was in the form of an oblong, V R (Fig. 81), and he argued that a second prism placed at right angles to the first would disperse the ray of light in a horizontal direction just as the first prism did in a vertical. But the actual result was that the spectrum retained its breadth but was transferred to another position V¹ R¹. And here again the violet portion of the spectrum was more refracted than the red. But there was no further breaking up of any of the colours. They remained as before.

192 The Wonders of the Spectroscope

If white light can be split up by a prism into the beautiful series of colours known as the spectrum, it is not unnatural to suppose that a combination of all these colours will give us white light again. If we place a second prism (Fig. 82) near the first and parallel to it, but in a reverse position, the light will be no longer coloured. By mixing the original colours we have produced white light again.

When Newton produced his original spectrum by passing a ray of light through a round hole and receiving it on a prism, he produced an image which was very bright and brilliant, but it had one fault—the colours seemed to melt and run into one another. It was difficult to say where any

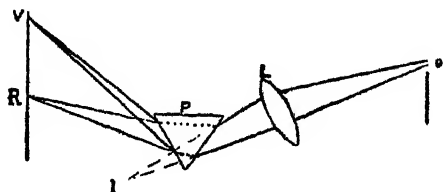


FIG. 83. THE PRODUCTION OF A PURE SPECTRUM

particular one ended and where the next began. It was an impure spectrum.

In order to remedy this defect Newton adopted the following measures. He placed a convex lens, *L*, (Fig. 83), some distance from the hole *O* so that it formed an image of it at *I*. He then placed a prism *P* between the lens and the screen and refracting the rays produced a purer spectrum *R V*, in which all the colours of different wave-lengths were more distinctly separated. But in order to obtain the best results it is better to substitute a narrow slit for the round hole.

Let us now substitute for the screen a telescope and we at once get a much better working arrangement than before, in fact we have made for ourselves a simple form of that wonderful instrument the Spectroscope. If we make use of a prism made of flint-glass we shall, on looking through



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COAL-TAR DYES IN PHOTOGRAPHY.

Two interesting comparisons between Ordinary (right) and Wratten Panchromatic Plates with "K" screens (left), in photographing objects whose colours require to be represented in correct relative value in monochrome.

The Wonders of the Spectroscope 193

the telescope, observe a broader spectrum than if we used a crown-glass prism, which has only half the dispersive power.

In the annexed illustration (Fig. 84) we give the general outlines of a simple spectroscope which embodies the following features :

A prism, P, is fixed on a stand supporting a tube, B, which is furnished with an adjustable slit, S, at one end and a lens, L, at the other, which renders the rays parallel before they pass into the prism. The telescope, T, consisting of an object-glass and sliding eye-piece with two lenses, receives the rays after they have passed through the prism. Here we observe the spectrum of any desired object. There is

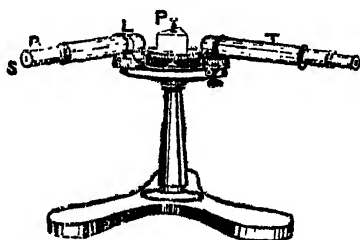


FIG. 84. THE SPECTROSCOPE

sometimes another tube, not shown, which contains a scale which is reflected from the prism, and serves as a standard of measurement on viewing a spectrum. The slit, which is actuated by a micrometer screw, may be furnished with a reflecting prism by means of which two spectra can be shown in the field of view at the same time. This is useful for comparison purposes, as for instance in comparing the lines of a known substance with those of a body under examination. In order to get greater dispersive power we may make use of a chain of prisms distributed in a circle (Fig. 85).

A very convenient instrument which is easy to use and simple in construction is the "direct-vision spectroscope" (Fig. 86). It can be made small enough to be carried in the pocket, and consists of a tube, A, with a lens, L, and a com-

194 The Wonders of the Spectroscope

pound prism, P, with a brass disc and eye-hole in front. This slides in and out of a larger tube, T, with an adjustable slit at one end S.

This convenient little instrument is very useful for many of the simpler experiments in spectroscopy. It shows the Fraunhofer lines, the spectra of metals, gases and other interesting objects. It may be provided with a micrometer

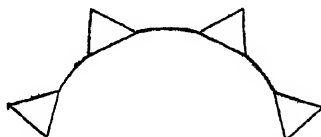


FIG. 85. A CHAIN OF PRISMS

scale which is reflected by means of a magnifying prism into the field of view, so that it appears parallel with the spectrum. The value of the instrument is thereby much increased.

If we look at a candle flame through such an instrument we shall observe a continuous band of different coloured rays stretching from red right away to violet, and a very beautiful sight it is. There we see white light



FIG. 86. POCKET SPECTROSCOPE

separated out into its constituent colours with a beauty of splendour and hue which must be seen to be appreciated.

Now, certain chemical bodies, as we have before remarked, send out coloured rays of light when strongly heated in the colourless flame of a Bunsen-burner, or of a spirit-lamp. A little Salt will colour the flame yellow, Chloride of Lithium will render it red, Potassium Salts will tinge it with a violet hue, and so on. This is all very beautiful and very fascinating, and it leads us on to ask ourselves what is the nature of the light which is emitted by these coloured flames. The

The Wonders of the Spectroscope 195

answer is that the prism in our spectroscope will analyse the light for us and reveal its secret. Each of the substances which we have used will give us certain bright lines—spectrum lines—which are characteristic of the particular body which has imparted its colour to the flame; and if we place in the flame a mixture of the various salts we shall see different lines corresponding to each of the various substances which we have employed.

Here we have the foundation of Spectrum Analysis, which not only reveals the composition of substances here on earth, but also tells us the chemical constitution of the sun, the stars and other heavenly bodies. We learn such profound facts as that at inconceivable distances away there are bodies which reveal the presence of elements which are known to us on earth, while there are others into whose constitution

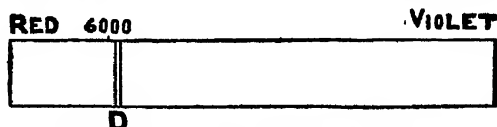


FIG. 87. THE D LINES OF SODIUM

there enter substances which are quite unknown to us here, and the delicacy of this form of analysis is very great. The characteristic yellow D line of Sodium (Fig. 87) which is resolved into two lines by a high-power spectroscope, can be detected in bodies which contain the element in infinitesimal quantities.

We have noticed, so far, two different kinds of spectra. The continuous spectrum of a candle flame due to the light given out by incandescent particles of carbon, and the bright D line of Sodium which is characteristic of a gas in an incandescent or glowing state—in this case the vapour of that element. It can be easily seen by placing a fragment of Salt on a platinum wire and introducing it into a spirit flame. A pocket spectroscope reveals the line well. There is, besides these two kinds of spectra, a third, which is of great significance. It is known as the Absorption Spectrum.

Suppose that we take a glass which is coloured blue and

196 The Wonders of the Spectroscope

examine it with a slit and prism, or with a spectroscope. We shall find that the spectrum presents a strange appearance. The red, orange and yellow have disappeared, and the green, blue and violet only are left. The blue glass has absorbed the rest of the coloured rays (Fig. 88). If we take a red glass we shall find that only the red and orange rays will be transmitted. The green, blue and violet colours will be absent. If we examine both the glasses together we shall get no effect at all. Each glass will absorb just the very colours which the other transmits, and the result will be that no light will pass through them.

These Absorption Spectra tell us that coloured glasses have the property of holding back or absorbing some of the rays of light while allowing others to pass. And we see similar effects in the case of coloured liquids. Thus a

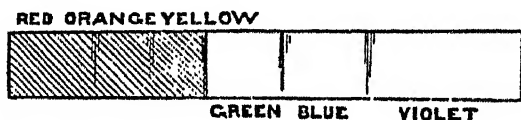


FIG. 88. RED, ORANGE, AND YELLOW RAYS CUT OFF BY A PIECE OF BLUE GLASS

solution of Potassium Bichromate stops all the blue, green and violet and allows only the red and yellow light to pass. A solution of Potassium Permanganate gives a very interesting result. A number of dark absorption bands is seen in the green portion of the spectrum. And there are numerous other substances, both solid, liquid and gaseous, which give us these characteristic spectra. Thus Iodine, if heated to produce a vapour, gives a spectrum containing a number of dark absorption lines.

We have seen that many metallic salts, such as those of Sodium, Lithium, Strontium and others, give characteristic flame colourations and bright line spectra when heated sufficiently so that their glowing vapours may be examined. And the presence of the metals in those salts is at once detected by the spectroscope.

The Bunsen flame, however, by the aid of which most of

The Wonders of the Spectroscope 197

these spectra are obtained, is not of sufficiently high temperature to yield a spectrum of the majority of the metallic elements. It is necessary to employ either the electric spark or the electric arc in order to volatilise them, and so render their vapours luminous. For many purposes the spark method of working is very convenient. An induction coil, I (Fig. 89), is connected up by wires to two terminals, T T, the points of which may consist of the particular metal under examination. These are brought close to each other, and the slit of the spectroscope is illuminated by the spark. A Leyden jar, L, should be connected with the coil in order to increase

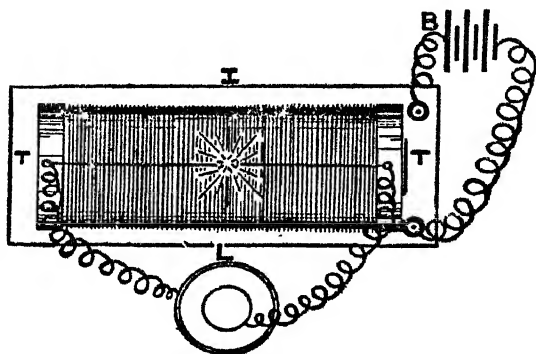


FIG. 89. METHOD OF OBTAINING THE SPECTRA OF METALS

the temperature of the spark. The outside coating of the jar is connected to one terminal of the coil and the inside to the other. B is a battery which works the coil. A short thick and brilliant spark gives excellent spectra, especially with such metals as Zinc, Iron and Copper.

In the electric arc method two-pointed Carbons are connected by wires to a powerful battery or a dynamo, brought into contact for a moment and then separated with the formation of a brilliant discharge between the two electrodes. This is of sufficient heat to volatilise any ordinary metallic salt placed on the point of the Carbons, and to give a spectrum consisting of the vapour of the metal under examination.

198 The Wonders of the Spectroscope

The spectra of gases are generally obtained by passing an electric discharge through a special tube (Plücker tube) (Fig. 90), which may be fitted with two stop-cocks for the introduction of any desired gas at a very low pressure. The gas is intensely heated up in the capillary portion of the tube by the discharge from an induction coil. The spectra obtained by this means are very beautiful. Thus Hydrogen gives a characteristic series of red, green, blue and violet lines, and the whole tube glows with a bright red light. In addition to these bright line spectra Plücker has shown that some gases, such as Nitrogen, exhibit two different kinds of spectra under varying conditions. We have the ordinary spectrum of lines as in the case of Hydrogen, and also one consisting of fluted bands, which are very attractive. We shall come across this special form again later on.



FIG. 90. TUBE FOR SHOWING THE SPECTRA OF GASES

We have already seen that the visible spectrum occupies only a very small portion of all possible radiations. At the violet end of the ordinary spectrum of light there lies a region which stretches far beyond—the Ultra-violet. Our eyes are not attuned to those short wave-lengths, which are finally lost in those dim etheric recesses where we believe the Röntgen rays have their origin. How are we to explore these hidden regions? One way is by making use of certain bodies which exhibit what is known as Fluorescence; Light of very short wave-length, invisible to our eyes, when it falls upon a substance such as Sulphate of Quinine, or upon Petroleum or Chlorophyll, etc., suffers a change. Its normal rate of vibration is lowered, and the atoms of the fluorescent body begin to oscillate, and thereby give rise to waves of

The Wonders of the Spectroscope 199

lower refrangibility which are able to excite the human retina. A screen, therefore, of some fluorescent material, if a spectrum be cast upon it, will reveal by its pale light the presence of rays quite beyond our ordinary vision. There are many sources of Ultra-violet light such as sun-light, the electric spark, the brush discharge of an electric machine, Geissler tubes and others. Since ordinary glass absorbs these radiations it is necessary to equip a spectroscope with lenses and prisms of quartz, which allow these short waves to pass. At the same time the dispersion is greatly increased. It is thus possible to see the Fraunhofer lines (dark lines on the spectrum) on a fluorescent background, and otherwise to examine that interesting region of invisible light. Then, too, photography can be called to the aid of the investigator ; by its means Schumann discovered those rays of infinitesimal wave-length which bear his name.

On the other side of the visible spectrum beyond the red there is another region of wave-lengths, this time too long for human vision. It is the Infra-red portion of radiation which descends down and down with ever-increasing wave-length to regions where electric waves have their birth and beyond. And between the shortest Hertzian waves and the longest waves of the rays whose energy by absorption is transformed into heat, there is still an unexplored gap of what is comprised under the head of Radiant Heat. As with Ultra-violet light, there are several ways of exploring this hidden region of the Infra-red.

Melloni in his researches made use of the Thermopile invented by Nobili. This depends on the principle discovered by Seebeck, that if two dissimilar metals like Bismuth and Antimony be soldered together and their ends connected up by wires to a sensitive galvanometer, an electric current flows round the circuit if the junction of the metals be warmed. Such a current is called a Thermo-electric current. In the Thermopile a large number of pairs of Antimony and Bismuth are united together with their ends exposed as at A (Fig. 91) and provided with a conical reflector. This makes a very sensitive instrument when

200 The Wonders of the Spectroscope

joined up to a galvanometer for detecting radiation of different kinds.

A still more sensitive instrument is the Bolometer invented by Langley. This will measure rays which are far beyond the limits of the visible spectrum on both sides. This depends upon the principle that if one or two delicate strips of platinum, faced with lampblack to increase their power of absorption, be exposed to any form of radiation either in the visible spectrum or otherwise, it will become by absorption slightly warmed. This will upset the balance of an electric circuit by causing a change in its resistance, and a current being set up it will cause a very delicate and sensitive galvanometer provided with a mirror, to reflect a

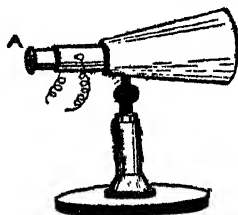


FIG. 91. THERMO-ELECTRIC PILE

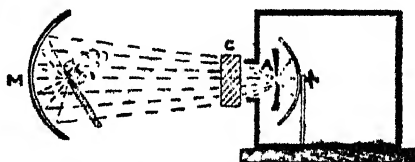


FIG. 92. SETTING FIRE TO WOOD BY MEANS OF INFRA-RED RAYS

beam of light in the form of a spot upon a suitable scale, or upon a photographic plate.

These Infra-red rays are present not only in the sun's spectrum, but also in the arc-light, and are emitted by all heated bodies. Since they are a form of "invisible light" they obey the ordinary laws of light, and can therefore be reflected, refracted, and so forth. They traverse opaque objects such as Ebonite. Tyndall demonstrated their presence in a very striking way. Using an arc-light, A (Fig. 92), he cut out all the visible rays by means of a glass cell containing Iodine and Carbon Disulphide, C, and brought the invisible "dark-heat" rays to a focus in a mirror, M, where they set on fire a piece of wood.

For a complete study of the Infra-red rays and of the heating effects of this form of radiant energy it is necessary

The Wonders of the Spectroscope 201

to make use of prisms and lenses of rock-salt, since much of the radiation is absorbed by ordinary glass. Fluor-spar is also used.

The energy of light manifests itself not only in heat but also in chemical action. Plants by the action of light are able to tear asunder the Carbon and Oxygen atoms of the Carbon Dioxide present in the air for the purpose of building up their structure. And it is the red rays which are mainly responsible for the decomposition. And on the other side of the spectrum in the violet and Ultra-violet regions there are other rays which cause chemical action, this time in the Salts of Silver. This is the basis of photography. To-day we have plates sensitive to the whole spectrum and beyond, so that the area of chemical action has been much enlarged.

CHAPTER XIX

WHAT THE SPECTROSCOPE TELLS US ABOUT THE SUN AND OTHER HEAVENLY BODIES

THE spectrum of sunlight with its fascinating colours which pass from red all along to blue and violet in orderly gradation, reveals to us further characteristics which are of profound importance in any study of the subject. For besides those alluring colours which all should see, we find that the spectrum is crossed by a number of dark lines which were the special object of investigation by Fraunhofer. He found that they were present in very large numbers, and that some were broader and darker than others. Moreover, they were to be seen not only in the emission or continuous spectrum of

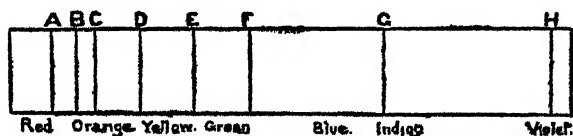


FIG. 93. THE CHIEF FRAUNHOFER LINES OF THE
SOLAR SPECTRUM

the Sun, but also in the spectra of the Moon and the Stars. It is true in these latter that they were not quite the same as regards their position and their intensity as those lines seen in the spectrum of the sun, but they all pointed to the conclusion that the cause of the phenomenon lay in the heavenly bodies themselves. For it was not possible, so Fraunhofer found, to detect these mysterious dark lines in any continuous spectrum of terrestrial incandescent solids. He mapped out a large number of the dark lines and assigned to the chief ones the letters of the alphabet (Fig. 93). Thus A, B and C are in the red portion of the spectrum,

The Sun ☉ other Heavenly Bodies 203

D consisting of two parallel lines close to each other lies in the orange-yellow, E in the border line between yellow and green, F in a position where the green shades off gradually into blue, G in the indigo portion of the spectrum, and H far into the violet.

Fraunhofer not only mapped the dark lines but he also measured their wave-length. This, as has been already mentioned, is the distance from the crest of one wave or undulation to the crest of the next as is denoted by the letter λ (Fig. 94), and the frequency of any wave is expressed in terms of the number of waves which pass a given spot in one second. But since the little particles which constitute the wave movement are like corks, bobbing up and down on

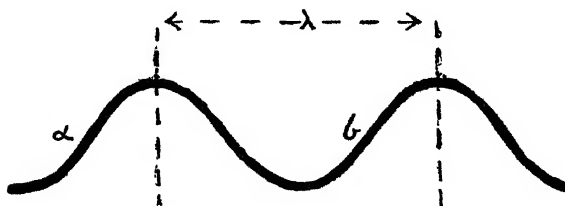


FIG. 94. WAVE LENGTHS

the surface of rippling water, so, too, the distance from any particle to the next which is in a similar position, and moving in the same direction, is a measure of the wave-length, as for instance A to B in the figure.

In order to measure the wave-lengths of the dark lines Fraunhofer made use of another method of splitting up light into its component parts. He used what is known as a Diffraction Grating. Suppose that we examine the light of a candle by means of two very fine slits, one in front of the other, we shall notice a beautiful image consisting of a bright central band which is the image of the slit flanked on both sides (Fig. 95) with a number of coloured bands, alternately bright and dark and becoming less pronounced as they gradually shade off to the right and left. The result is due to light passing through the slits and penetrating into

204 The Sun ☉ other Heavenly Bodies

the geometrical shadow on either side ; there they produce what are known as Interference effects. In other words, we must imagine that the waves of light will in some cases unite with one another, crest with crest, and strengthening one another will produce bright bands, while at other points uniting in unlike phases, crest with trough, will annihilate each other and produce dark bands. And if we view these bands through coloured glasses, say red and blue, we shall find that the dark bands of the red image are further apart than those of the blue image, proving thereby that the red rays have a greater wave-length than the blue.

Now a Diffraction Grating consists of a very great number of narrow slits arranged close to each other, and Fraunhofer constructed some by ruling a large number of close, equi-

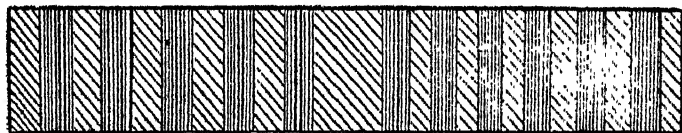


FIG. 95. DIFFRACTION SPECTRA

distant parallel lines on sheets of glass. They gave a series of spectra in which the colours are differently distributed in comparison with the ordinary colours of the prism. In these latter the blue is much dispersed, while the red, yellow and green are all crowded together. In the diffraction spectrum the distribution of the various colours is in terms of their wave-lengths (Fig. 96). And by determining the position of the lines Fraunhofer measured the wave-lengths of the dark spectral lines found when sunlight is examined through a spectroscope. For instance, without quoting all, he found that in the celebrated D line there were more than forty-three thousand waves to the inch, with a rate of vibration or frequency of over five hundred billions per second.

If the lines composing a Diffraction Grating are carefully ruled by a diamond point on hard polished metal it is possible

to crowd more than twenty thousand into one single inch ! Working with such gratings the different wave-lengths of light can be calculated very accurately.

In order to test some of the dark spectrum lines of the sun, and especially the D line, and its possible coincidence with that seen in the spectrum of the glowing gases of the arc-light, Foucault caused an image of the sun to fall on the arc, and saw that the two lines coincided. The gases absorbed the very rays which they gave out, revealing what is known as the "reversal" of the spectrum. Dark lines take the place of the bright ones. This is of very great

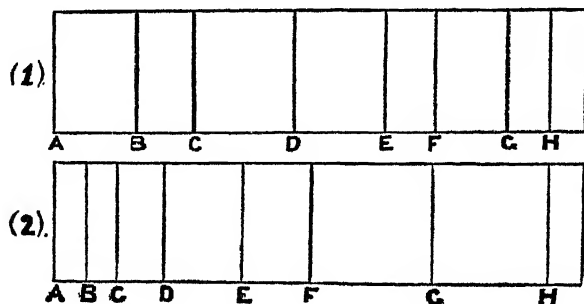


FIG. 96. (1) DIFFRACTION SPECTRUM.
(2) PRISMATIC SPECTRUM

significance. These dark lines must be caused by white light passing through the glowing vapour of Sodium present in the Sun's atmosphere. And this is not an isolated case. We know by the researches of Kirchoff that there are other dark lines which occupy the same position as the bright lines of various metals, such as Iron, Copper, Calcium (line H), Potassium, Strontium and many more. Gases, too, reveal their presence. Thus lines C, F and G coincide with Hydrogen. A and B are known as "telluric" lines (*Tellus*, earth, Lat.), and are absorption Oxygen bands caused by the rays of the sun when low down on the horizon passing through a layer of aqueous vapour present in the atmosphere of the earth. The light, too, which reaches us from distant stars show absorption spectra. How far away these shining

206 The Sun & other Heavenly Bodies

bodies are ! Yet they reveal to us through all the realms of space, the secret of their composition. Moreover we know that the gases which intercept and absorb the rays of light passing through them must be at a lower temperature than the source of those radiations. Otherwise absorption and radiation would balance each other, and the dark lines would disappear, or we should get bright lines as the result of a higher temperature.

And bearing this in mind, if we wish to reproduce this beautiful phenomenon in the laboratory we must first get a very hot source of light, such as the arc-light, to represent the photosphere of the sun which lies beneath the glowing atmosphere vapours, and a Bunsen-burner of lower temperature containing Sodium in a vaporized condition. The dark band is then seen very clearly—the absorption spectrum of Sodium.

The principles which underlie this are very interesting, and we must just look at them for a moment.

Suppose that we take two tuning-forks which are in unison, and place them close to each other. Let us sound one, and after stopping the vibrations let us attentively listen. The other fork, set in vibration, gives out the same note as the first one. It is vibrating in harmony or in resonance with it, since its period of oscillation or frequency is similar to that of the first. Or consider this analogy.

If we take two precisely similar balls of equal size and weight and hang them to a wire between two supports (Fig. 97) by equal lengths of string, and set them swinging, their frequency of oscillation will be the same. Each will swing backward and forward with the same natural period of vibration.

Let one ball be at rest and set the other in motion. What happens ? The stationary ball will begin to oscillate in sympathy or resonance with the first, and soon it will be seen to swing backward and forward, while the oscillations of the first one gradually die down. But directly this happens the second ball assumes the rôle of the first and begins to set it in motion, while its own vibrations gradually die away.

The Sun ☉ other Heavenly Bodies 207

And so it goes on until the two vibrating systems come to rest.

So also we must imagine the electrons in the vapour of Sodium capable of oscillating with a certain time-period or frequency of their own—more than five hundred billion per second. When white light traverses the vapour the electrons, being subjected to periodic impulses of the same rate of vibration as their own, will respond through resonance, and will vibrate with such energy that they will absorb that of the electrons corresponding to that particular wave-length. Thus instead of bright lines we get dark lines by reason of this absorption.

We have seen that the application of the spectroscope

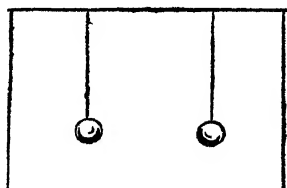


FIG. 97. SWINGING BALLS
ILLUSTRATING THE PRIN-
CIPLE OF THE REVERSAL OF
THE SODIUM LINE

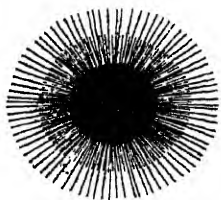


FIG. 98. THE CORONA OF
THE SUN AT THE TIME OF
AN ECLIPSE

to the analysis of sunlight revealed to us the fact that there are elements in the sun which are known to us on earth, and that all these have characteristic spectra. And the reversal spectrum of Sodium (and other elements) tells us that there must be a solar atmosphere of glowing vapours, and that inside this must lie the actual surface of the Sun—that brilliant surface which is called the Photosphere. Rowland of Baltimore, with the aid of his Diffraction Gratings, made an exhaustive map of the spectral lines in the Sun. He identified an extraordinary number of terrestrial elements. Thus in the case of Iron alone, he accounted for more than two thousand lines.

At the time of an eclipse when the Moon intercepts our view and interposes itself between the sun and our earth,

208 The Sun & other Heavenly Bodies

it is possible to get some idea of its surroundings. The phenomena attendant on such eclipses are very striking. From the chromosphere or gaseous envelope of the sun there flash forth "Prominences," as they are called, to a height which occasionally extends to two hundred or three hundred thousand miles. At the same time a radiant halo which is called the "Corona" surrounds the eclipsed sun (Fig. 98) sending out rays in all directions which penetrate to an enormous distance, even to some millions of miles. Let us look at these different aspects of the sun, and see in what way the spectroscope has helped to reveal their secrets.

There is no doubt that the prominences (Fig. 99) consist of gases in a luminous and glowing state--lurid flames or clouds which reveal their presence in bright line spectra. Many of the early observers saw these lines quite clearly



FIG. 99. PROMINENCES

when there was no eclipse, and their position in the spectrum, which corresponds to those of the dark Fraunhofer lines, has been determined, i.e. C, F, G (near), and *h*, the spectrum of Hydrogen.

Although the prominences are for the most part of a rosy colour, it is possible to observe them in the light of any particular wave-length. Thus they can be observed and examined in the light of the F line or C line. In other words, in light of one colour only, monochromatic. A prominence seen in the light of the F line will appear to be blue-green. This has been made possible by the employment of a very ingenious instrument—the Spectroheliograph, invented by Professor Hale.

The light given out by a particular wave-length reaches the photographic plate through a second slit which is so arranged that it excludes all the rest of the spectrum, and

The Sun & other Heavenly Bodies 209

allows only this definite wave-length to pass. The image of the sun or prominence is allowed to pass across the first slit of the spectroscope, which is of large dimensions, slowly and uniformly by means of a small motor which moves the telescope. At the same time the photographic plate is moved along in unison with the sun's image, giving in this way an image in monochromatic light of any wave-length desired. According to Evershed it is possible to establish the presence of two distinct kinds of prominences, eruptive and quiescent, and the spectroheliograph tells us that "the position of prominences is not confined solely to the edge of the sun but that they are distributed all over the solar surface." There are also markings known as "Flocculi" which have been photographed—clouds of Calcium vapour as seen by light from K. Some, however, are dark, and are closely connected with the prominences.

Helium is one of the constituent gases of the prominences. Since it is one of the disintegration products of Radium we must infer that that famous element is present also in the sun.

The Chromosphere, or enveloping cloud of gaseous vapour round the sun, shows the same bright lines as are revealed by the prominences, if viewed (as Lockyer has indicated) on a faint extended spectrum so as to cut out the light due to reflection and diffusion. Among the lines is one characteristic of the element Helium; other elements also reveal their presence. Two notable lines, H and K, are due to Calcium. Huggins found that the varying changes seen in these lines and in others given by the same element, were due to varying densities of the vapour present in the chromosphere. Deslandres added an ingenious addition to the spectroheliograph—an instrument which may be styled a "speedometer." This indicated the speed at which the gaseous vapours of the chromosphere are ascending and descending. Later observers have recorded eruptive outbursts of Hydrogen of short duration. Photographic records have been obtained also of a curious phenomenon seen on the occasion of an eclipse. The "Flash Spectrum"

210 The Sun & other Heavenly Bodies

is a sudden reversal of the dark absorption lines into bright line spectra which vanish as quickly as they come.

The Corona, when we look at it in the spectroscope, reveals a line in the green which is attributed to an unknown element—Coronium. There is also a continuous spectrum which points to the presence of incandescent bodies. Other bright lines are caused by Magnesium, Sodium, Iron and Titanium.

Let us now look at those interesting objects called Sun-spots. The modern theory of sun-spots is based upon the knowledge which the spectroscope has conferred on workers in different observatories throughout the world. They tell us that these objects are columns of gas which, rising from the interior of the sun like gigantic tornadoes or water-spouts, and expanding by reason of their rapid rotation, "produce a comparatively dark cloud, the umbra, which we see in the sun-spot." They are gaseous vortices. Hale announced that he had discovered the existence of a magnetic field in these spots, and Maunder has established a connection between them and terrestrial magnetism. It would appear that magnetic storms are coincident with the presence of sun-spots which are electrical in character.

The Stars, those myriad lights of the heavens—what can we learn about them? Fraunhofer, who examined the light given out by various stars, found certain dark lines as he had previously done in the case of the solar spectrum. Although they were not always alike, there seems no doubt that when these dark lines are seen, judging from the analogy of the solar spectrum, they must be caused by a photosphere emitting light which is afterwards absorbed by a gaseous atmosphere outside. Of course, the light is much more feeble than that of the sun. Even the brightest star of all, Sirius, is many thousand million times less bright than the sun itself. However, he showed that similar elements existed in the atmosphere of stars like Arcturus, Capella, Aldebaran and others, as those discovered in the sun. The work was carried out by means of a telescope, and a simple prism

placed in front of the object glass. This gave a very narrow spectrum, which added to the difficulties of the task.

When, later on, Huggins and Miller took up the investigation, they substituted a narrow slit for the prism, and placed it in the focus of the telescope together with a lens and prism—a spectroscope—and the resultant image was broadened out as much as possible by a special cylindrical eyepiece. Numerous elements were discovered in the spectra of stars by these means. Hydrogen revealed its presence in most of them. The spectrum (Fig. 100) reveals five lines, one in the red, one in the blue-green, the third in the indigo, and two away in the violet.

Secchi found that the stellar spectra could be grouped in four main divisions, and in one of them the Hydrogen

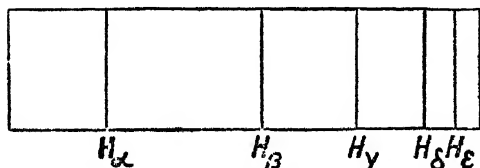


FIG. 100. THE SPECTRUM OF HYDROGEN

lines were wanting. There were added a few stars distributed in the Milky Way to form a fifth group, and there are others which give a bright line spectrum of Hydrogen. These form, perhaps, a small class of their own.

Group I includes white or bluish stars of which Sirius and Vega are examples. The former is the brightest of all the stars, and within the first six of those which are nearest to us on earth. The spectrum of the Hydrogen lines is dark and broad, but the metallic lines due to the presence of Calcium is weak. Vega (alpha Lyrae), a star of the first magnitude, has also a weak Calcium line, but a large number of Hydrogen lines are seen, and from researches it has been found that all these bear a simple relation to each other. This has been extended to the spectra of other elements such as Potassium, Lithium, etc., which can be divided up into three distinct series connected with one another.

212 The Sun & other Heavenly Bodies

In Group II there are a number of stars of which Arcturus and Capella are types. They are yellow in colour. Arcturus (alpha Boötis) is a very bright star and its spectrum discloses Hydrogen lines clear and dark. There is also a strong Calcium line.

Group III includes orange stars like alpha Orionis, (Betelgeux) which is another very bright star, whose spectrum reveals Sodium and Magnesium and a number of fluted bands which are very prominent in the blue end of the spectrum, but which shade away towards the red. It has been shown by Fowler that these interesting bands are due to the presence of Oxide of Titanium. They are also present in sun-spots.

In Group IV are to be found certain red stars, not very bright, which show fluted spectral bands shading off towards the violet—a reverse direction to that of the stars of the previous group. They are due to the reversal of a Hydrocarbon or a Carbon Monoxide spectrum, which in comets is seen as a bright line spectrum of three lines, two of green and one of blue. Piazz Smyth, who investigated the spectrum, considered it to be due to the Oxide of Carbon. He denoted the position of the lines in terms of what he called “wave-numbers,” or the number of waves lying in any definite length such as an inch. And Alexander Herschel showed that these wave numbers could be arranged in two “similar arithmetical series, the fifth of the first series coinciding with the first line of the second.” These and other relations suggested that there was a law governing them, just as we have seen in the case of Hydrogen and the alkaline metals. Thus the spectrum is a very important one.

Group V contains stars as Rigel (beta Orionis), whose spectrum reveals the presence not only of Hydrogen, but also that of Helium, which is found, too, in the atmosphere of the sun. These Helium stars are generally found in the region of the Milky Way, that wonderful part of the heavens which Milton calls the “Galaxy . . . powdered with stars,” and which Aristotle thought was the result of all kinds of earthly vapours blazing in the sky.

The Sun ☼ other Heavenly Bodies 213

There are certain stars which may be included in a small group (Group VI) which give bright line spectra of Hydrogen. A typical member of this little community is beta Lyræ, which is another Helium star.

From time to time certain mysterious stars have appeared in the heavens which have shone for a time, some with various colours, and have then faded away. The brightest of all was the *Nova*, or New Star (*novus*, new, Lat.), named after Tycho Brahe, which is said to have been as bright as Venus. It lasted for a year and a half. They all exhibit the bright line spectra of hydrogen and helium, and also a line in the green which is due to the presence of what has been called "Nebulium," an unknown constituent of the nebulæ.

TCoronæ, as a very faint star, rose in brightness to that of a star of second magnitude, and then gradually faded. It showed a bright line spectrum, and it is interesting to note that the "prominences" seen in a total eclipse of the sun give the same bright line spectrum, as also the "chromosphere," thus suggesting that stars, too, possess prominences and chromosphere. And this agrees with the theory of Huggins that the Novæ are the result of an outburst of hot matter from the interior of the star. Barnard also points out that one of the chief characteristics of the Novæ is that in their early stages they give a crimson image which is due to a vast outbreak of Hydrogen. Other Novæ have appeared in the Great Nebula in Andromeda, in Cygnus, in Auriga, and a very brilliant one in Perseus, which photographic evidence led to the belief that in its later stages it had given birth to a nebula.

There are some stars whose brightness is not a fixed quantity. They vary from time to time. One of the best known is Algol. From a second magnitude star it changes in brilliancy almost to one of whole magnitude, the entire period involved being about two days twenty hours. The theory that the variability is caused by an eclipsing companion which describes an orbital path round it was confirmed by Vogel, who showed that the dark companion satellite was moving at a speed of nearly thirty miles per

214 The Sun & other Heavenly Bodies

second. This he did by the aid of the spectroscope, for by its use it is possible to determine the motion of bodies as they approach or recede from us. It was Doppler who laid down the principle on which such determination is based. Thus, "when the distance between us and a body which is emitting regular vibrations either of sound or light is diminishing, then the number of pulsations received by us in each second is increased and the length of the waves is correspondingly diminished," and vice versa.

We see a cyclist approaching us on the road ringing his bell, and we notice that the pitch rises gradually until he passes us, when it gets lower and lower. In the one case, that of approach, the effect is to shorten the wave-length and raise the pitch. More waves enter into our ear. When receding, less waves enter and the pitch falls. Apply the analogy to light. Suppose that we have a green light source approaching us. The light given out will be that of a gradually increasing frequency of oscillation with a diminishing wave-length. Thus the green will tend to become slightly blue in colour. In the case of a star spectrum, or indeed of that of any moving body in the heavens, what is seen is a slight displacement of the spectral lines, say that of the hydrogen line towards the red end (receding) or towards the violet (approaching) of the spectrum. Of course, the shifting of the lines is very very small, and the whole observation is a very delicate one. In the case of Sound the phenomenon is easy to observe since the velocity of sound is so small compared with that of light—a little more than a 1000 feet per second compared with 186,000 miles per second! Hence any change of colour, and therefore of wave-length, corresponding to the change of pitch of a cyclist's bell is quite out of the question. Yet, the ringing of the bell—one of the commonplaces of life—leads us on to profound conclusions involving a very beautiful application of the spectroscope. And the principle has been used to determine not only the velocities with which stars are approaching to or receding from us, but also such questions as the law which governs the Sun's rotation, Saturn's rings, etc. In this latter case it

The Sun ☉ other Heavenly Bodies 215

has been shown that of the two theories, (1) that the rings are stationary, or (2) that they consist of a swarm of small satellites, the latter is the correct one. The displacement of the spectral lines of the inner edge of the revolving rings towards the violet shows that the velocity is greater here than at the outer edge.

In the case of so-called "Spectroscopic Binaries" or double stars such as beta Aurigæ, composed of pairs which at certain periods in their orbital path are found to be moving across the line of sight, there is no displacement. At other times there is a shift towards the violet in one star and towards the red in the case of the other, thus proving their approach and recession respectively. Another interesting

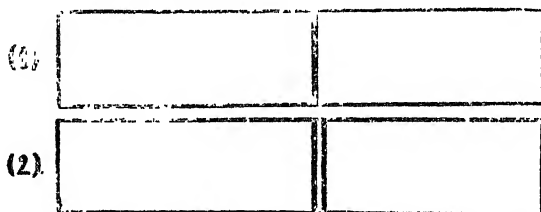


FIG. 101. (1) Across the line of sight. No displacement.
(2) Displacement of line. Approach and recession.

binary, beta Lyræ, discloses the fact that the component members alternately eclipse each other, going through these changes in thirteen days with two maxima and minima. In the annexed illustration is a graphic representation of the principle involved (Fig. 101). The discovery of the spectroscope and the great advance in the science of photography has shed new light upon the heavenly bodies. To the telescope has been added all the wonderful instruments of these later years with a corresponding increase of knowledge.

The telescope has not revealed to our sight more wonderful objects in the heavens than the Nebulæ, those misty objects, faint, ethereal, luminous, which shine with the stars in the far-off depths of space. They exhibit different forms, some of which are exceedingly striking and impressive,

216 The Sun ☉ other Heavenly Bodies

There are some of annular form (*annulus*, ring, Lat.). Others are elliptical in shape like the Great Nebula in Andromeda. Some adopt the spiral form, some like the Great Nebula in Orion are diffused irregular patches of light. All are unequally distributed. Around the poles of the Milky Way they are most abundant.

The story of the discovery by Huggins of the spectrum of a Nebula is most dramatic. For the first time he had directed his telescope to one of the planetary Nebulæ in Draco—what he saw astonished him. Instead of a spectrum extended out completely “it remained concentrated in a single bright line.” And a further examination revealed two other bright lines on the side towards the blue, all the three lines being separated by intervals relatively dark.” The bright line spectrum was that of an incandescent gas. As Huggins says, “the light of this Nebula had clearly been emitted by a luminous gas.” And after further description of this momentous discovery, he goes on to say that in the far-off ages of time the “matter now condensed into the sun and planets filled the whole space occupied by the Solar System in the condition of a gas which appeared as a glowing Nebula.”

It was found later that not all the Nebulæ give the spectrum as seen by Huggins. Some disclose continuous spectra. Those which exhibit the bright-line spectrum owe it to an element peculiar to Nebulæ—Nebulium. There are lines to be seen both in the green and the violet, but the chief Nebulium line is a very bright one in the green. It has not been found in any earthly substance. Nicholson in a communication to the Royal Society suggests that it is one of the simplest type of elements whose atom is represented by a nucleus of positive electricity surrounded by revolving electrons, those little negatively charged units of electricity, which vibrate around the atom, just like the sun and the planets of the Solar System.

The early spectra of Comets showed a very characteristic spectrum of fluted bands suggestive of Hydrocarbon constituents. Later spectra exhibit lines in the ultra-violet

The Sun ☼ other Heavenly Bodies 217

portion of the spectrum. These have been put down to the presence of Cyanogen-gas. Some have revealed the presence of Sodium, some the characteristic lines of Iron, thus associating them with meteors. Some, too, have given a continuous spectrum.

The generally accepted theory of Auroræ is that they are due to the projection from the sun at high velocity of electrons which on entering the earth's magnetic field are given a definite path. Indeed, it has been shown experimentally that Cathode rays, which consist of negatively electrified particles, exhibit phenomena usually associated with Auroræ. The chief line in the spectrum, in the green, is still the object of much controversy. It has been put down to Argon and Krypton. Other bright lines have been assigned to Nitrogen, to Coronium, an unknown element present in the corona of the sun, etc. There is also a Hydrogen line.

CHAPTER XX

CARBON AND SOME OF ITS COMPOUNDS

THE number of compounds into the composition of which the element Carbon enters is so great that it has been customary to include them into one general group under the head of Organic Chemistry. And this, too, more for the sake of convenience than because of any definite boundary between them and inorganic bodies. In the early days of chemistry a sharp distinction was drawn between the terms "Organic" and "Inorganic" as applied to compounds included under these two heads. Men looked abroad upon the face of Nature and saw all the wonderful compounds produced in the organs of plants and animals, produced by vital processes, by the agency of living things, and they naturally came to the conclusion that there must be some distinction between them and those compounds which are not dependent for their origin upon "vital force."

The distinction to which we have alluded was in a great measure the result of the barrier which was erected between the living and non-living. To-day, although we cannot say that that barrier has been removed, and that the origin of life has been discovered by the chemist in his laboratory, yet we may affirm that the dividing line is not so sharp and distinct as it was once supposed to be. But the problem has not been solved. Whether life can be produced by chemical and physical processes is no concern to the worker in pure chemistry. The interest is centred in the domain of bio-chemistry (*bios*, life, Grk.) and biology. But, be this as it may, the distinction between organic and inorganic compounds has certainly broken down very much, and, for

Carbon & some of its Compounds 219

this reason. Many of the compounds of Carbon can be produced artificially in the laboratory to-day quite independently of any so-called "vital force." The number, too, of these substances is increasing every day. The triumphs of modern synthetical chemistry are seen in all departments of life. We have artificial or synthetic drugs, scents of all descriptions, dyes, foods, drinks, etc., ever increasing in bewildering array, and the end is not yet. When Urea, a typical organic compound usually thought to be obtained only from the bodies of animals, was artificially produced by Wohler, the ball was set rolling, and it has continued to roll ever since. It was the first breach in the wall which had hitherto been considered invulnerable. It is possible now to produce synthetic compounds which resemble, and are very loosely related to, those products styled Peptones which are formed in the human body by the action of the gastric juice, containing small quantities of an organic body called Pepsin. Thus the reaction which set in against the supporters of the theory of "vital force" has been very much strengthened. The fight has been carried right into the enemy's country.

Most of the Carbon compounds are formed by the union of that element with Hydrogen, Oxygen and Nitrogen in varying proportions, and it is wonderful, when we come to consider it, the number of chemical changes which can be rung, and the prodigious array of bodies which can be formed by the combination of Carbon with so few elements.

Without considering the artificial compounds, we may say that Carbon is an exceedingly and widely diffused element. We meet with it everywhere in natural combination, in all organic structures of animal and vegetable life, in the air we breathe, in vast mountain ranges as limestone, chalk, etc., in the depths of the earth as coal, and elsewhere. And we have seen that it is present also in the heavenly bodies. And just as we saw in the case of such an element as Phosphorus that it can exist in different forms or modifications—known as allotropic—so, too, in the case of Carbon we have such bodies as the Diamond and Graphite

220 Carbon & some of its Compounds

or Plumbago, which seem so entirely different that it is difficult to imagine at times that they are only divers forms of the same substance.

The Diamond is the purest form of Carbon and occurs in a crystalline condition, sometimes in the form of octahedra (Fig. 102). It is the hardest substance known. That it consists of Carbon is seen by the fact that it can be burnt away in Oxygen-gas (as Lavoisier showed) or converted into a black mass like coke in the intense heat of the electric arc. This heat may rise to temperatures as high as 7000° , which is very much greater than boiling steel. At this temperature such a metal as Platinum, which is most refractory, melts quite easily. In ordinary blast-furnaces in which special means are taken to raise the temperature, the limit is about

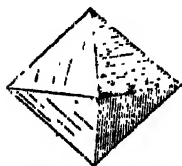


FIG. 102. OCTAHEDRAL FORM OF DIAMOND

3000° . The electric furnace stands by itself, therefore, in the artificial production of very high temperatures. At Niagara, with the power derived from the Falls, there are a large number of these furnaces which manufacture aluminium from clay, unite those infusible elements, lime and coke into Carbide of Calcium, and turn out large quantities of Carborundum, which is used for grinding metals.

Moissan, utilizing the great heat of the electric furnace, actually produced artificial diamonds. He took Iron, and after saturating it with Carbon and strongly heating it, he suddenly cooled it. By this means he produced an enormous pressure by the contraction of the outside solid portion of the mass on the interior solidifying metal, so that part of the Carbon content assumed the form of the diamond. The gems produced by this process were quite microscopic in size. Even the largest were only about .5 millimetre in diameter.

Graphite is a modification of Carbon. The common name is black-lead, a dark, friable substance with a metallic lustre. It is very soft and is used in the manufacture of pencils. It is often found in the crystalline form, like the

Carbon & some of its Compounds 221

diamond, generally in the shape of hexagonal or six-sided plates. It is produced artificially to-day in the electric furnace from Charcoal.

This substance with Graphite and the Diamond constitute the three allotropic modifications of Carbon. It is obtained from wood by subjecting it to partial combustion in a kiln or pile of wood so arranged that only a limited supply of air can come in contact with the burning material. The volatile compounds of Carbon with Hydrogen and Oxygen are driven off, and charcoal is left behind. It is a black non-crystalline substance which burns in air forming Carbon Dioxide or Carbon Monoxide according to the perfectness of the combustion. In its purest form it is known as Lamp-black, which is deposited on any cold surface from a smoky flame. In chimneys it occurs in a less pure state as Soot. Coke is another form of Carbon, and is obtained as a by-product in the production of coal-gas. Bone-black is an impure form of animal charcoal obtained from bones. Charcoal is an exceedingly porous substance, and advantage is taken of this property in many ways. It is able to absorb various gases in large quantities. One volume of coco-nut charcoal will absorb more than one hundred and seventy volumes of Ammonia-gas, and even ordinary charcoal will absorb Oxygen in the ratio of one volume to nine volumes of the gas. Here lies the secret of its purifying powers when used in filters and as a disinfectant. Offensive gases and disagreeable substances are at once oxidized and changed with the consequent loss of smell. Its action is purely a chemical one.

Then, too, it is largely used in the refining of sugar since it has the power of removing colours from liquids. For this purpose bone-black is chiefly used, and by its use the dark-coloured syrup which is obtained from the cane in the early stage of manufacture is decolourized. Again, in the production of high vacua where vessels are required to be exhausted of air very completely, the principle of absorption has been utilized at the suggestion of Dewar for this purpose. When the Mercury pump has done its work, the remaining

222 Carbon & some of its Compounds

gas is absorbed by charcoal with the aid of liquid air. By this means Dewar has reduced the pressure in a vessel to 0.000,008 mm. of Mercury. When we consider that the average weight of the atmosphere will support a column of Mercury seven hundred and sixty millimetres in height, we can form some idea of the extreme tenuity of the residual air in such exhausted vessels. We all know that wood gradually decays in air; in water and in damp ground its deterioration is still more rapid. But charcoal preserves its structure for longer periods. Hence wood which has been charred—piles, for instance, immersed in water—does not suffer decay in anything like the same way as untreated material.

The carbonaceous rocks of the earth contain the decayed remains of vegetable life which have accumulated through vast ages of time—geological epochs—and form the product known as Coal. The process was one of successive stages, from decaying wood and vegetable matter to peat, lignite and various forms of Coal, all distinguished by their varying content of Carbon, Hydrogen and Oxygen. Thus, anthracite contains more Carbon than ordinary Coal, but less Oxygen and Hydrogen. The volatile liquids—by-products in gas-making—known as coal-tar are black and evil-smelling. That they should give rise to those enchanting colours comprised in dyes of a thousand hues and shades, is one of the marvels which Science reveals.

It is very difficult to get Carbon to combine directly with Nitrogen, but by passing Nitrogen over a mixture of some form of Carbon and an alkaline carbonate like Potassium Carbonate there results, under the influence of a high temperature, a compound called a Cyanide—in this case Potassium Cyanide. From this can be formed Mercury Cyanide. If we heat this compound we get the colourless gas, Cyanogen, given off. It is soluble in water and inflammable, burning with a purple flame. It is very poisonous. Some of its compounds are blue, hence its name (*kuanos*, blue, Grk.). It combines with Hydrogen to form that exceedingly dangerous substance, Hydrocyanic or Prussic

Carbon & some of its Compounds 223

Acid, which occurs in Nature in the leaves of the laurel, etc., in this case, of course, in very minute quantities, since one drop of the pure acid is fatal. It has the characteristic smell of bitter almonds. The Cyanides of Silver, Potassium and Gold are largely used in electro-plating. Prussian Blue, which is extensively used as a pigment, is a double Cyanide of Iron.

Carbon combines with Hydrogen to form a host of compounds known as the Hydrocarbons. For the purpose of this book it will be sufficient to look, first of all, at three members of three distinct groups or series. They are Marsh-gas, Ethylene and Acetylene.

Mention has been made before of Marsh-gas in connection with explosions in mines under the name of "Fire-damp." When these disasters take place a large proportion of deaths occur from poisoning, from "choke-damp," or Carbon Dioxide, but the explosions themselves are started by Marsh-gas or Methane, which is present in large quantities in Coal, especially when newly raised. We need not be surprised since the percentage of Hydrogen in the gas is so high. Mixing with air it forms a highly explosive mixture. As its name suggests, it occurs in Nature wherever vegetable matter decays in the presence of water. It burns with a blue-yellow flame.

Methane may be prepared artificially by heating Sodium acetate with an alkaline base like Caustic Soda. If we take away three atoms of Hydrogen from Methane and substitute three atoms of Chlorine we shall get a very important compound which is known as Chloroform.

This well-known substance, from a medical point of view, is a heavy sweetish liquid with a pleasant ethereal smell. It has a peculiar physiological action, causing temporary insensibility to pain, and is largely used as an anæsthetic. It may be prepared by heating alcohol with bleaching powder.

Now, we can substitute three atoms of Iodine in the same way and we get another important compound—Iodoform.

This substance is used largely in surgery as an antiseptic.

224 Carbon & some of its Compounds

It is a solid yellow crystalline body which is soluble in alcohol and ether. It may be prepared by heating alcohol with Sodium Carbonate and Iodine.

We have mentioned Alcohol several times, and since it is one of the derivatives of Methane, we must look at it a little more closely. It exists in a number of different forms.

When wood is heated in retorts gaseous and liquid products such as Marsh-gas, Hydrogen, Carbon Monoxide, Tar, Pyroligneous Acid (crude Acetic Acid), Wood Spirit, etc., are formed. The latter is separated out by distillation with lime and Sulphuric Acid, and there results a colourless liquid which burns with a pale blue flame. Its properties

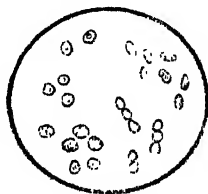


FIG. 103. YEAST IN VARIOUS STAGES OF GROWTH

resemble those of common alcohol. It is called Methyl Alcohol or Wood Spirit.

Ethyl Alcohol, known as Spirits of Wine or Common Alcohol, results from the fermentation of sugar. This sugar may be derived from many sources. Grape Sugar or Glucose, which is found in fruit juice, honey, etc., when dissolved in water and subjected to the action of yeast, is decomposed into Carbonic Acid and Alcohol.

Yeast is really a lowly plant of simple form like the Algæ, and consists of thousands of minute little cells which under suitable conditions reproduce themselves with great rapidity, by a system of budding, into a chain of cells (Fig. 103). Now, yeast gives rise to certain substances called Enzymes, nitrogenous bodies which cause chemical changes to occur in many different ways and under different circumstances. There are many kinds. The particular body with which we are immediately concerned is called Zymase.

Carbon & some of its Compounds 225

But there are others. For instance, in the saliva of the mouth Ptyalin is the active agent which is responsible for converting starch into a form of sugar. Then we have Diastase, which is able to convert starch into maltose and dextrin. It may be obtained from germinating barley. Another enzyme is Pepsin, which is contained in the gastric juice of the body, and the ultimate product is Peptone, the result of the splitting up of Protein, one of the organic compounds contained in ordinary food. Another interesting enzyme is Rennet which, added to milk, causes it to curdle with the formation of "junket."

Fermentation is therefore the first stage in the manufacture of alcohol, but the product at first obtained is impure and weak. It is necessary to have recourse to distillation in order to get a more concentrated spirit, which may be afterwards subjected to rectification in order to separate out as far as possible the water content. The purest form of alcohol thus obtained is known as Absolute Alcohol, which is a colourless spirituous liquid with a hot, burning taste and of intoxicating properties. It is highly inflammable, burning with a blue non-smoky flame. Alcohol is largely used as a solvent of resins, organic bodies of different kinds, and enters largely into the composition of varnishes, tinctures of all sorts, and perfumes. Ordinary "methylated spirit" is a mixture of ordinary alcohol with a certain percentage of wood spirit or some other allied body which will render the liquid unfit for drinking purposes. Alcoholic beverages contain various percentage amounts of the pure spirit in them. Thus in beer of a mild form the alcohol present is about 3 per cent. Claret contains 7 per cent, whisky, brandy, rum, all contain a large percentage, from 30 per cent upwards. A good class of stout or porter will have an alcoholic content of 6 per cent and over. Proof-spirit contains about 50 per cent of the pure spirit.

If alcohol be mixed with Sulphuric Acid and carefully distilled, a very light colourless liquid possessing a strong vinous smell is obtained. This is known simply as Ether. It is exceedingly inflammable, and as its boiling-point is

226 Carbon & some of its Compounds

only about 34° , great care is necessary in handling it. Its vapour spreads rapidly and forms with air a very explosive mixture. It is largely used as an anæsthetic either by itself or mixed with chloroform. It is an excellent solvent for all kinds of fats, resins and other bodies.

Aldehyde or Acetic Aldehyde, as it is sometimes called, is the result of oxidizing alcohol. It is alcohol minus two atoms of Hydrogen, and is a colourless volatile liquid with a peculiar smell. It possesses strong reducing properties since it unites easily with Oxygen. Paraldehyde is a modification, occasionally used in medicine, and is the result of the change which comes when Aldehyde is left to itself for some time.

If we substitute three atoms of Chlorine for three of Hydrogen in aldehyde we get a colourless liquid—chloral—with a powerful smell. If we add water to this we obtain a very important substance, Chloral Hydrate. This crystallises out in colourless prisms which are used in medicine for inducing sleep.

If the vapour of wood spirit (methyl alcohol) be passed with air over heated Platinum a colourless gas is obtained which dissolves in water, forming a solution known as Formalin. This has the property of rendering gelatine insoluble in water. Hence it is largely used by photographers, especially in warm climates, to prevent "frilling" of the edges of plates and films. It is used also as a preservative and disinfectant.

If Formaldehyde (Formalin) be oxidized a colourless liquid with a strong penetrating smell is obtained. This is Formic Acid, which occurs naturally in ants, hence its name (*formica*, ant, Lat.).

We have seen that alcohol is the result of fermentation of sugar through the action of minute organisms which are contained in what is called yeast. Now alcohol itself can be subjected to a form of fermentation which transforms it into acetic acid. This is known as acetic-acid fermentation. And, speaking generally, there are many organic bodies which can be fermented if there are present the necessary

Carbon & some of its Compounds 227

organisms or "ferments," which, finding a suitable medium for their growth, are able to induce chemical changes and decompositions.

Acetic fermentation is often spontaneous. Beer, for instance, if left exposed to the air for some time, becomes acid in character. Its alcohol has been changed into weak acetic acid solution. So, too, wine becomes sour for the same reason. Indeed, "wine-vinegar," as it is called, is made in this way by exposing a cheap wine of poor quality to the action of atmospheric air. But in all these cases, some outside agent is necessary, some aerial germ to induce the chemical change. In this case a minute and microscopic fungus, the *Mycoderma Aceti*, is the bearer of the Oxygen from the air which is necessary for the alcohol to absorb before fermentation can take place.

Sometimes barrels or large casks are partially filled with vinegar in order to obtain a large quantity of the Mycelium growth. After being emptied they are filled with weak wine and left to ferment. An infusion of malt is also used. But all these processes are slow. A quicker method is to cause a stream of weak alcohol to trickle through casks filled with beech-wood shavings previously sprinkled with vinegar. At the same time a current of air is blown through the shavings, and all the time the temperature is carefully regulated so as not to exceed about 77° F. A certain amount of alcohol is always present in the final product and acetic acid, whose content varies from 3 to 5 per cent. Colouring matter is added sometimes. The fragrance of high-class vinegar is due to the presence of small traces of ethereal salts. A great deal of cheap vinegar is nothing more than acetic acid with some colouring matter and a little flavouring. Pure acetic acid is a colourless liquid with a sharp but not unpleasant smell, and a strong acid taste. Below 16° it forms an ice-like mass which is known as Glacial acetic acid. It forms soluble compounds with Aluminium and Iron, which are used in calico printing and in dyeing generally. With Lead it forms lead acetate, an important salt, known also as Sugar of Lead. Then there

228 Carbon & some of its Compounds

is Acetate of Copper, which is popularly known as Verdigris. Both of these substances are poisonous.

In order to prepare the strong acid, Sodium Acetate is taken and distilled with Sulphuric Acid. By repeated cooling and distilling it is possible to get a very strong product. When wood is heated in retorts a large quantity of acetic acid of low strength comes over which, by the addition of soda, is converted into the acetate, which is then subjected to further distillation.

Ethereal Salts are important bodies. Suppose that we add an acid like Sulphuric to Potassium or Sodium Hydroxide, we shall get a Sulphate of Potassium or Sodium, as the case may be. So also, taking ethyl alcohol, which is really a hydroxide, and treating it with acetic acid we get an ethyl salt, the acetate. So, too, with methyl alcohol. Possessing as they do fragrant and pleasant odours, these ethereal salts are responsible for many of those delightful perfumes which it is the object of the chemist to build up artificially for our use to-day.

Soap is an interesting and well-known chemical compound. Let us take some tallow, a fat made up of glycerin and an acid called Stearic. If we boil it up with caustic potash we get as products glycerin and an oily mass which is soap. There are two kinds, hard and soft. The former is made from caustic soda, the latter from caustic potash.

Ethylene must now claim our attention. This gas which belongs to a distinct series of Hydrocarbons, has a number of derivatives like Methane. It is one of the products of the decomposition of coal when heated in retorts at the gas-works. Indeed, it gives to coal-gas one of its main illuminating constituents, since it burns, itself, with a bright, though smoky flame. Thus it differs from Methane, for it contains twice as much Carbon, all of which is not burnt completely owing to limited combustion. A laboratory method of preparing it is to take alcohol and remove the water content by means of an agent like Sulphuric Acid. Sometimes this gas is called Olefiant Gas (*oleum*, oil; *fio*, become, Lat.), since it combines with Chlorine and Bromine,

Carbon & some of its Compounds 229

forming oily compounds such as Ethylene Chloride and Bromide. From these it is possible to get a number of compounds resembling sugar, in their sweetness, such as Glycol (Ethylene alcohol), and Glycerol (Glycerin), both colourless oily liquids whose names are Greek derivatives (*glukus*, sweet), thus giving a clue to one of their chief properties.

CHAPTER XXI

THE STORY OF CARBON COMPOUNDS—*continued.*

THE humble Fire-worshippers of Baku, in Southern Russia, lowly pilgrims from India, falling down in deep abasement before the Everlasting Fire—how little did they dream of what those mysterious flames portended! We know to-day—the rise of a great Industry! To-day in place of those jets of flame which history tells us have ever darted up here and there above the surface of the ground, deep wells are sunk whence millions of gallons of crude oil are yearly conveyed to the refineries. The Indians are gone. Hardly one stone remains upon another of the temples where they worshipped the Eternal Fires, but the oil-wells of Russia and America, Burma and Hungary are centres of enormous commercial activity. For this is the age of Petroleum for Light and Power—and of Petrol. Crude Petroleum consists of hydrocarbons which on distillation yield a large number of different products. They all come under the head of what are known as “Paraffins.” In other words, they are hydrocarbons which are inert bodies, and are not affected by such agents as acids or oxidizing substances (*parum*, little; *affinis*, taking part in, Lat.).

Some of these paraffins have already been noticed, such as Methane and Ethylene. They are gaseous, as also some of their derivatives such as Ethane, Butane, Propylene and others. There are also a large number of liquid products which may be separated and divided out according to their specific gravities or boiling-points. Among the lighter bodies are found Gasoline and Benzoline (benzine) with petrol. These have low boiling-points. Then there is Naphtha and a number of products used for illuminating

The Story of Carbon Compounds 231

purposes—such as paraffin, kerosene, etc., all very useful substances in their way. Lubricating oils of different kinds are also obtained, as well as some solid products such as paraffin wax, vaseline and others.

Among organic compounds the vegetable or fruit acids have an important bearing on the economy of life.

Tartaric Acid is found in the juice of the grape, generally in combination with potash, forming Potassium Tartrate or Cream of Tartar. When fermented juice is left for some time this substance separates out from the liquid and is deposited as a "crust" on the sides of bottles and casks. This deposit increases by age, and thus the wine tends to become less acid. Year by year it matures, and its value increases accordingly.

Tartaric Acid is found not only in grapes, but also in fruits of all kinds, and there is no doubt that their health-giving properties are largely due to the presence of such acid bodies as tartaric, citric and others of the same class.

If a mixture of Tartaric Acid and Bicarbonate of Soda be dissolved in water, a tumultuous rush of gas in sparkling bubbles occurs, and the liquid becomes highly charged with Carbonic Acid gas. Such a mixture is known as Seidlitz Powder. It is a well known pharmaceutical product.

Tartaric Acid forms a number of salts with Potassium, Sodium, etc., some of which are of importance. Thus with Potassium it forms what is known as "Cream of Tartar," and a mixture of Sodium and Potassium Tartrates is known as Rochelle Salt; with Antimony and Potassium it forms Tartar Emetic. Another acid which is found naturally in plants, especially those of the Oxalis tribe, such as Wood Sorrel (*oxalis acetosella*), is Oxalic Acid. It is probably for this reason that animals leave these kinds of plants untouched. In the juice of fruits also we find the acid. Also in rhubarb leaves. In the late war a great many people cooked the leaves as well as the stems of this popular vegetable, forgetting that Oxalic Acid is a poison and that there is quite a large amount present in rhubarb, with the exception of the stems.

232 The Story of Carbon Compounds

Citric Acid is extensively used in making lemonade. Although this acid is found in many kinds of fruit, yet its chief source is the juice of the lemon. From this it is obtained in the crystalline form which is soluble in water.

Malic Acid derives its name from the Latin *malum*, an apple, its original source. Rhubarb, berries of the mountain-ash, and the juice of many other kinds of fruit are the principal sources of this substance.

We must now look at a very important compound of Carbon and Hydrogen, a hydrocarbon called Acetylene. This useful gas, which is employed so extensively to-day both for illuminating purposes and together with Oxygen in the welding of iron, steel and other metals, is one of the products of the destructive distillation of coal, and as one of the constituents of coal-gas it contributes very much to its illuminating effects.

In the intense heat of the electric furnace it is found that Lime and Carbon in the form of coke, etc., two very infusible substances, unite to form a greyish solid which has revolutionized the manufacture of Acetylene. By the simple action of water, the gas comes off quite easily, so that it can be produced in enormous quantities and with little trouble. The grey substance is called Calcium Carbide.

One of the drawbacks to the use of Acetylene in private houses is its unpleasant smell, which resembles that of leeks or garlic. This is obviated to a great extent by good workmanship in the installation. Burning as it does, naturally, with a smoky though bright flame, it requires to be ignited in special burners when used for illuminating purposes. It is poisonous, and forms with copper an explosive compound.

When Acetylene is heated it gives rise to a number of products which illustrate a very important principle in any extended study of organic substances. One of these products is Benzene, which is a hydrocarbon with important derivatives. Now its formula shows that although its molecular weight differs from that of Acetylene, yet it has the same percentage composition. Hence it is styled a Polymeric

The Story of Carbon Compounds 233

substance (*polus*, many; *meros*, part, Grk.). In the same way there are bodies which contain the same elements united in the same proportions and with identical molecular weights, yet they often differ from one another; these are called Isomers (*isos*, equal; *meros*, part). Thus Ammonium Cyanate if dissolved in water and heated is transformed into a substance called Urea, with exactly the same formula. Thus from Carbon, Oxygen, Nitrogen and Hydrogen, inorganic elements, Wöhler formed an organic compound by purely artificial means. Even Acetylene can be made from Carbon and Hydrogen by means of the electric arc. By such methods was the barrier broken down between inorganic and organic bodies. And it led also to the conclusion that it is not so much a question of the atoms which enter into the composition of any particular body, as of the arrangement and the grouping of them to form a particular molecular structure which differentiates one compound from another. Carbohydrates, considered more fully later on (Chap. XXII), must be referred to here.

Such bodies as Sugar in its various forms, Starch and Cellulose, come under this head, and will be now briefly considered. The term applied to these substances is somewhat misleading. They consist of Carbon, Hydrogen and Oxygen, the two latter united in the same proportion as in the case of water. Thus starch has double the number of Hydrogen atoms as of Oxygen in its composition. But the rule is not absolute, and there are anomalies which have to be considered.

Cane Sugar is found in the sugar cane, honey, sugar maple, beet, etc. As prepared from the cane, the juice is crushed out by rollers and, after the addition of a little lime, it is boiled in vacuum pans, filtered and evaporated down until it crystallizes out. This constitutes brown sugar. On further evaporation and crystallization, treacle is obtained, which is further refined. The process is simplified by use of centrifugal machines which throw out the liquid and leave the crystalline mass behind. This is again dissolved in water and filtered through charcoal to remove

234 The Story of Carbon Compounds

colouring matter. It is then evaporated down again in vacuum pans under reduced pressure and run into moulds or simply dried. If cane sugar be heated it becomes converted into Caramel. It belongs to the mono-clinic system of crystals.

The manufacture of sugar from the beet has been carried on for many years on the Continent, but it has not been taken in hand to any great extent in England. The process of extraction is not quite the same as obtains in cane sugar. The beetroot after having been sliced is suspended in water into which fresh slices are continually introduced so that the solution gradually becomes richer in sugar, which passes through the cellular structure of the beet by diffusion. Then lime is added, and after filtration and evaporation, the sugar is refined by charcoal and then boiled down in vacuum pans, and crystallized out by centrifugal force.

During the late war attention was directed to the sugar-beet, and attempts were made to obtain a syrup from it for domestic purposes. It was quickly seen that the extraction of a solid product was out of the question, since the process is highly technical and requires special machinery in order to carry it out. However, syrup was made, and in some cases a crude form of crystal sugar. It was used for sweetening purposes on a somewhat large scale. But only about 5 per cent of sugar in any form was obtained from the root, and it is questionable whether the results obtained justify all the time and labour required to be expended on the process of extraction.

Sugar of Milk or Lactose is a form of sugar found in milk. If the liquid portion of so-called "junket," the "whey" as it is termed, be evaporated down we get Lactose in the crystalline state. It is less sweet than ordinary sugar. Now, when milk "turns" or becomes sour, the sugar contained in it, by the actions of germs, becomes converted into Lactic Acid. This causes the milk to "curdle" by precipitating the albuminous substance in it, called Casein. This is the first step in making cheese.

Suppose that we take some barley and allow it to ger-

The Story of Carbon Compounds 235

minate in the presence of water, and then dry it off. It will be found to contain an enzyme called Diastase, which is a powerful agent of fermentation. It has the power of converting starch into Maltose and another substance called Dextrin. This substance, Maltose, it will be noticed, is a sugar having the same formula as Sugar of Milk, and, like it, is not so sweet as sugar obtained from the cane.

Glucose or Grape Sugar is found in a natural state in many fruits, especially in the grape. If a raisin be opened a number of white crystalline granules will be seen within. These consist of grape sugar. When honey is allowed to stand for some time, a crystalline substance separates out which is identical with grape sugar. In many kinds of fruit, as the ripening process goes on, they become less sour, and when mature contain a quantity of Glucose mixed with Fructose, which is another fruit sugar. In the case of a fruit like the greengage, the sugar content is high, but often, as in the apple, there is still a little acid left, and this renders the fruit refreshing to the palate.

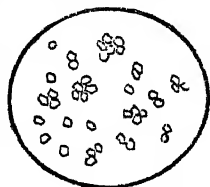


FIG. 104. GRAINS OF RICE STARCH

Starch is a familiar substance found in potatoes, grain of all kinds, in various fruits, etc., and is formed by plants by assimilating Carbon Dioxide and water under the action of sunlight. It consists of little granules or grains, and these are found in a number of different forms. In Chap. XXIII, Fig. 115, are depicted grains of Potato Starch. In the annexed diagram (Fig. 104) are seen the angular grains of Rice Starch. When heated in water these little grains burst asunder and we get a thick solution which is known as Starch Paste. Since ordinary wheaten Flour contains over 60 per cent of Starch, excellent paste can be made from this material.

If Starch be heated to about 150° or treated with a dilute acid such as Hydrochloric, it is converted into an isomeric substance called Dextrin. This is soluble in water and may be used in the place of gum. Now,

236 The Story of Carbon Compounds

if this solution be boiled with Sulphuric Acid, it is converted into glucose which, as we have already seen, is contained in the juice of fruits. Large quantities of this form of sugar are manufactured from potato starch. The acid is removed by lime and the liquid filtered and boiled down to a syrup or to a solid (grape sugar). In the manufacture of jam, large quantities of this syrup are used for sweetening purposes. It is also used in the process of silvering mirrors, since it reduces the salts of silver. And we have seen that if it undergoes fermentation it is converted into Alcohol. Since glucose can be obtained from numerous substances such as paper, woody fibre, rags, cotton, etc., the production of sugar, and consequently of Alcohol, is not

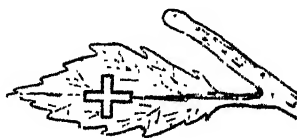


FIG. 105. PART OF A LEAF PROTECTED FROM LIGHT TO PROVE THE ABSENCE OF STARCH WHEN TESTED WITH IODINE

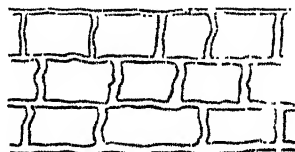


FIG. 106. CELLS OF A PLANT

confined to merely one or two sources. A very delicate test for the presence of starch is that afforded by Iodine. If to a little starch paste a few drops of an alcoholic tincture of Iodine be added, a blue colouration will show the presence of the carbohydrate. The same test may be applied to leaves which only manufacture starch by the assimilation of Carbon in the presence of light. Hence if part of a leaf be covered with a design (Fig. 105) and left for twenty-four hours, the Iodine test will reveal the presence of starch only in the exposed portion of the leaf. Hence a silhouette of the cross or any other figure will be obtained.

If we examine with the microscope the vegetable tissue of any plant we shall find it to be composed of a number of little cells (Fig. 106) separated from one another by divisions or cell walls which consist of what is known as

The Story of Carbon Compounds 237

Cellulose. If we take some of this tissue in the form of saw-dust or any woody fibre and remove the impurities by the use of suitable solvents, it is possible to obtain a colourless material which is pure cellulose. Cotton wool, flax, etc. are good examples of this substance which is largely used for textile purposes of every kind.

Enormous quantities of wood pulp, consisting mainly of cellulose, are imported from Sweden and Norway, and used for the manufacture of paper. One of the great London Dailies obtains its own supply direct from the forests of Newfoundland. Artificial silk, parchment paper (paper treated with Sulphuric Acid), celluloid, photographic films and many other products are all cellulose in one form or another. It may also be converted into dextrin and glucose, and from thence into alcohol as we have seen, so that there is no end to the scope of its application. Nor must we forget its use in the manufacture of Gun-cotton (Chap. xxiv).

We have seen that the old distinction between Inorganic and Organic Chemistry has broken down by reason of the fact that so many purely organic bodies are now made artificially from inorganic elements. This is the age of Synthetic Products, and in Industrial Chemistry the effect has been very great. We may not, as Sir William Crookes once said, achieve synthetic beef or synthetic mutton, but as soon as Berthelot, the great French chemist, and Wöhler set the ball rolling, the number of these artificial substances, dyes, drugs, foods of all kinds, sugars, perfumes and what not, increased yearly. In this section some synthetic drugs will be noticed. The dwarf evergreen plant known as Winter Green (*Gaultheria procumbens*) contains an essential oil in which Salicylic Acid is found in the form of Methyl Salicylate, an ethereal salt. By treating the oil with caustic potash artificial salicylic acid results. There are also other ways of producing it from purely inorganic elements. It is used as an antiseptic and is useful in rheumatism. A drug closely allied to it is Aspirin. Then there is Salol, also used as an antiseptic.

238 The Story of Carbon Compounds

Veronal is a well known soporific, and Sulphonal is also used for the same purpose.

Phenacetin and Antifebrin are other modern drugs extensively used in medicine. They are artificial products.

When we purchase all these artificial drugs and all those dainty pharmaceutical preparations which form a large part of the stock of modern chemists to-day, we must remember that they are the fruits of labour and toil in unseen laboratories, by men who wrest from Nature herself secrets long guarded. From all kinds of unlikely sources there come triumphs of modern chemistry, transformations brought about by that wonderful process called chemical change.

Menthol is allied to camphor and occurs naturally in oil of peppermint. It can be synthetically prepared.

There are some Alkaloids which we will now consider. They are found in plants and are alkaline in character, hence their name.

Quinine is a valuable drug obtained from the Cinchona, and forms a number of salts such as the Sulphate, Hydrochloride, etc., with acids. If one atom of Oxygen be taken away we get what is known as Cinchonine, which is a milder form of Quinine.

Morphine is an alkaloid of Opium, and is the most active and the most valuable of all the different kinds which may be obtained from the juice of the poppy. The hydrochlorate is known as Morphia. Codeine is a derivative of Morphine.

Cocaine is a very dangerous drug. This alkaloid, which has of late years acquired an unenviable reputation, is found in the leaves of Erythroxylon Coca. It forms a salt with Hydrochloric Acid, and this is what is usually employed in medicine. It is curious that an artificial product has been obtained whose physiological action is almost nil.

The little bush with its white flowers and bright green leaves, native of Bolivia and Peru, has been famous since remote times for the effect which its leaves have on the system. Chewed or infused like tea, the aboriginal Indians found in it a source of gentle excitement, a retarding of the

pangs of hunger, prevention of breathlessness in climbing hills, and a source of nervous energy. The active principle which can be dissolved out from the leaves in crystalline form is contained in an apparently harmless white powder which has figured so prominently in many a *cause célèbre* during the last few years. Stringent rules now regulate its sale, and a doctor's prescription is absolutely necessary before this dangerous alkaloid, which is useful as a local anæsthetic and in other ways, can be obtained.

The leaf of another plant, *Nicotiana tabacum*, contains as the active principle Nicotine, an oily acrid poisonous liquid. A single drop is said to be fatal to a dog. Different tobaccos contain varying amounts of the alkaloid. It is present in the smoke from pipe or cigarette, but of course in very small quantity.

Strychnine is obtained from *Nux Vomica* and is one of the most poisonous of all the alkaloids. It is, however, extensively used in medicine, but only in infinitesimal doses.

CHAPTER XXII

CHEMISTRY IN DAILY LIFE

IN Chapter VI we gave some account of the air which we breathe into our lungs every moment of our lives, and we saw that it was a mixture of various gases: of these the chief constituents are Oxygen, Nitrogen and Carbon Dioxide in the proportions of 20.95, 79.02, and 0.04 volumes per cent respectively. And of these Oxygen is the vital element both for ourselves and for all animal life. The Nitrogen dilutes the more active gas, but it does not appear that it plays any further part in respiration.

The Oxygen of the air enters the blood through the lungs, those sponge-like organs which lie one on each side of the thorax or chest. They are composed of countless numbers of cellular cavities or air-sacs joined up by an enormous number of capillaries or hair-like vessels. Thus the Oxygen reaches the blood in the quickest and at the same time in the most complete manner possible, by the alternate expansion and contraction of the chest. On an average the amount of air drawn in and expired from the lungs in ordinary respiration amounts to about eighteen pints per minute, though it, of course, varies. When we take exercise, walking, running, swimming and the like, we make a greater demand upon our tissues, and Nature responds by causing us to breathe faster.

The blood is a very important factor in respiration. The way in which it performs its functions is very wonderful.

If we examine a drop of blood under the microscope (the more powerful the better), we shall find that it consists of a fluid, pale in colour, called the Plasma, in which float an enormous number of tiny little corpuscles, red and white.



CAPPING A SPOUTER AT THE OIL WELLS.

A workman in oil and gas-proof dress controls the tumultuous rush of oil by fixing a cap to the pipe, thus arresting the flow.

These are so small and so minute, that though the white are a little bigger, the diameter of the red is only about $\frac{1}{2500}$ th inch. In one drop there are countless numbers, and it is these little red bodies which give to blood its characteristic colour. They are round in shape, but slightly contracted in the middle, and have a tendency to join up to one another like a pile or column of coins or counters (Fig. 107). There are not so many white corpuscles in the blood as there are red, and their appearance is different, for they are transparent bodies with little dark nuclei floating in them (Fig. 108). The colour of the red corpuscles is due to a particular substance known as Hæmoglobin, which plays a very important part in respiration. It is able to combine with the Oxygen which we breathe into our lungs, just as we know

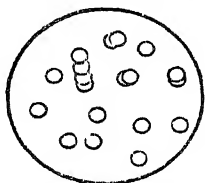


FIG. 107. RED CORPUSCLES.
Highly magnified.

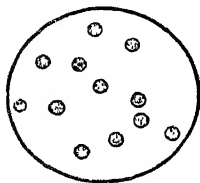


FIG. 108. WHITE CORPUSCLES.
Highly magnified.

that iron can combine or any other body to form an oxide. In this case the compound formed is known as oxy-hæmoglobin. And it is this oxidized blood which eventually reaches the tissues and other parts of the body. Thus the red corpuscles are the carriers of the gas.

When the blood has given up its Oxygen, it at once becomes darker in colour as we see it in the veins. The oxy-hæmoglobin has been reduced, and only recovers its power of combining with Oxygen when it has passed through the veins to the heart and from thence to the lungs once more. In the arteries, the bright red colour of the blood indicates that the Oxygen has not yet begun its work. When it has been carried along the life-stream to the tissues, etc., then its function begins. Now, when the Oxygen combines with the tissues of the body, a certain amount of

heat is developed, and it is this heat which helps to keep our bodies warm, generally at a temperature between 98° and 99° F. As the tissues burn away (if we may so use the expression) just like a piece of wood in a grate, their potential energy appears partly in this form of transformation, and partly in the form of work.

The Carbon in the tissues, when it combines with Oxygen, forms a waste product, Carbon Dioxide, and this gas is given out in our breath when we expire. The lime-water test (Chap. VII) is a proof of this. And the action is always going on. The body is always wasting (burning) away and therefore requires constant renewal of its parts. Does not the fire burn low in our grates with diminishing heat if we do not supply it at intervals with coal or other fuel? So, too, we must ever be inhaling Oxygen and taking in food of various kinds in order to counteract the destruction which is always going on, and to prevent those inevitable consequences of any neglect—cold, death.

In the light of all this, it is not surprising that the air exhaled from our bodies is found to have lost a considerable percentage of its Oxygen. At first it contained 20.96 volumes per cent. On expiration this drops to about 16 volumes per cent. At the same time it gains more Carbon Dioxide, about 4 per cent as compared with .04. There is also a certain amount of aqueous vapour present, the result of some of the Oxygen combining with the Hydrogen of the tissues (for besides Carbon they are made up of Hydrogen and Nitrogen). On any frosty day, or when we direct our breath upon a piece of cold glass, we can prove the presence of this moisture. The amount of Carbon Dioxide exhaled varies with the amount of work performed by the muscles and other tissues. The greater the oxidation which is necessary to repair the waste, the greater the amount of the gas expired. There are between twenty-seven and twenty-eight pounds of Carbon in every hundred pounds of the gas, and it is interesting to know that the human system gives out in the twenty-four hours half a pound or more of solid Carbon in the form of gas.

Ventilation is important in the light of these facts. It is estimated that every person should have at least 1000 cubic feet of space in any room for respiration purposes. Besides Carbon Dioxide, which affects the chemical purity of the air, there is in badly ventilated rooms heat and moisture which together with the stagnant air render the atmosphere unhealthy, and produce evil effects on the nervous system. And it is the opinion of a great many physiologists to-day that the condition of the air, looked at from a strictly chemical point of view, is not more important than those conditions which are associated with its temperature, degree of moisture, smell, etc. As far as an excess of Carbonic Acid is concerned, we know that a proportion greatly in excess of that usually laid down (about 9 parts per 1000) has not proved deleterious. Be that as it may, the necessity for adequate ventilation is not lessened by this theory or that which may be advanced in order to account for certain indisputable facts which themselves are not a question of argument.

Many and elaborate are the devices by which the purification and renewal of the air are attained by mechanical means and otherwise. From a chemical point of view it is interesting to glance at one of the latest methods of purifying air. Its underlying principle is the utilisation of Ozone, that curious allotropic modification of Oxygen-gas, whose molecule consists of three, instead of two atoms of Oxygen. One of these is ready to fly off at the least provocation; it splits off as it were and then enters into combination with other bodies, producing strong oxidation effects. Hence it has the property of destroying all kinds of harmful organic matter which is so often present in the atmosphere. This accounts for the purity of country air. Its utilisation in Hygiene and for industrial purposes is becoming increasingly prevalent. Some interesting particulars of the use of Ozone for pure air ventilation furnished by Ozonair, Ltd., who manufacture apparatus for the production of Ozone for commercial purposes of all kinds, are here given.

It has been shown (Chap. vi) that Ozone can be produced by

electrical methods on the principle of what is known as the silent discharge. In the ozone generators of this Company, atmospheric air is subjected to the action of an alternating current of electricity between electrodes of flat sheets of gauze consisting of a special alloy, and separated from one another by an insulating dielectric or medium of specially prepared material. This yields a comparatively large amount of Ozone at a voltage which need not exceed nine thousand in the highest concentrations. Since there are no chemicals used, and a supply of electricity is in these modern days obtainable almost everywhere, the use of Ozone for the purpose of ventilation, water purification, deodorising, etc., both for public and private purposes, is decidedly on the increase. Let us see how the system works, say, in the case of a hall or other public building, or any large room.



FIG. 100.
A SPARKLET

In the diagram (Fig. 110) the arrangement is as follows:—

Air enters at A, as clean and pure as possible, and is then washed and filtered by sprays of water, W, and a filtering screen, F, thus removing from it all deleterious gases. It then passes into the fan mixing chamber, M, connected up to a motor, E. Here it is purified by the addition of a small quantity of Ozone which is produced in the generator, O, of which T is the transformer, and conveyed to M by the pipe P. It is then discharged at D. It is possible to arrange so that the washer or screen is able to cool the air by many degrees, and for the purpose of warming it, a coil or radiator heated by low-pressure steam or hot water is fixed before the washer or filter screen. The Central London Railway have, in twelve stations, in the aggregate, over one hundred million cubic feet of cleaned and purified air introduced into them daily. This is one of the largest installations. Further details of the modern applications of Ozone are given in the last chapter.

Water, Hard and Soft, is another important factor in our daily life. As it percolates through the different strata of

the earth it is found to contain a large number of substances in the state of solution. Among these are the various salts of Magnesium and Calcium, Potassium, etc. Let us direct our attention to Calcium. In the form of Carbonate we find it in chalk, limestone, marble, etc., everywhere. Water cannot, of itself, take up into solution this salt ; but there is generally a little Carbonic Acid in solution which seizes hold of the Carbonate and forms the bicarbonate which is soluble. Now if we use soap with such water we find a difficulty in getting a good lather, and for domestic purposes it often leads to inconvenience. The soap forms with the Calcium Salt an insoluble Calcium Stearate, and a lather is only produced when all the Calcium has thus reacted. This takes time, and patience is not always unlimited.

The remedy is to use boiled water only in such cases. Then the excess of Carbonic Acid is driven off, and the insoluble carbonate is deposited in the kettle as "fur," and the water which before was temporarily hard is softened and fit for domestic use. Water which contains in solution Salts of Calcium and Magnesium as Sulphates is permanently hard, and cannot be softened by boiling. On a large scale lime is added to hard water, and the bicarbonate present is reduced to the soluble carbonate. Common soda is also used to augment the boiling of water in household use.

Let us now look at the question of Food. We take food every day for two reasons : (1) to help to keep our bodily heat and to repair the waste going on, and (2) to supply energy or power of doing work. All food contains Carbon and Hydrogen, and some contains Nitrogen. This last is classed under the head of Proteins, while the two former come under the head of Carbohydrates and Fats.

Proteins are complex nitrogenous substances of albuminous nature. They form the principal material of Protoplasm, that wonderful substance which is the base of all life. They constitute the flesh-forming portion of our food. They are found in both animal and vegetable foods, in white of egg, in blood and tissues, in meat and bread, etc.

Carbohydrates include Sugar, Starch and Cellulose,

which comprises much of the solid matter of vegetables, the outer skin of the wheat grain and of fruit.

Fats are contained in animal food, some fish, and in certain vegetables. These with carbohydrates are essentially heat and energy-giving foods. Let us examine some samples of ordinary food and test their values. We will begin with bread.

White flour is made from the interior of the wheat grain (endosperm, chiefly starch) and contains more carbohydrates but less fat than whole-meal flour made from the entire grain minus the "husk" or bran. It contains less proteins and is less nourishing. Moreover, those wonderful constituents called "vitamines" which by their nutritious influence play so important a part in whole-meal bread are absent in that highly refined flour which is so popular with all classes. Standard bread is excellent. So also is Hovis.

Flour mixed with water forms dough, which owes its stickiness to a protein (Gluten). Yeast converts the starch into sugar, alcohol and carbonic acid. On baking, the alcohol escapes, and the gas aerates the whole mass, making it light and spongy. Baking powder acts in the same way.

Oatmeal, whose protein content is higher than wheat flour, is very nourishing. Since it lacks gluten it cannot be made into bread.

Rice is very deficient in proteins, but its starch content is high. "Unpolished" rice, which contains most of the vitamins, is the most nourishing. Here again the demand for something highly refined does not coincide with the less popular but more nutritious form of this cereal.

Peas, Beans, Lentils are all very nutritious since they contain so much protein (double that of wheat). The starch content is high.

Potatoes contain about 75 per cent of water and are very deficient in proteins, but are fairly rich in carbohydrates—about 20 per cent. They are a useful food, but not very nourishing. They are, perhaps, the best food in comparison with green vegetables which contain so much water and

indigestible cellulose. These, however, with Fruit contain useful and pleasant salts which are good for the health.

Sugar is very sustaining and heat-producing, since its percentage of carbohydrates is so high. It is not nourishing.

Meat is very rich in proteins or nitrogenous food, but it contains so much water, 75 per cent, that it is not very economical in cooking, 15 to 20 per cent being lost in this way. Boiling, steaming and grilling are the least extravagant. Beef-tea is not very nourishing. Its proteins are all converted into gelatine, which is not a food, but for invalids it is stimulating and appetising.

Fish is a nourishing food, and in the case of salmon and herrings there is plenty of fat with a corresponding supply of energy.

Eggs are very nourishing. The "white" is mostly protein, and the yolk fat. They are quite equal to good fat beef.

Cheese is an excellent nutritious food, and superior to beef. Made from curds, it is rich in proteins and fats. With bread, supplying the necessary carbohydrates, it forms an admirable food, giving three times as much energy as beef.

Milk contains plenty of fat, carbohydrates and protein, but the water content is high, over 85 per cent, so that it is not a very concentrated food although an excellent one. If allowed to stand the fat rises to the top as Cream. Rennet causes it to curdle, forming "curds and whey." The former contains most of the protein (casein) and fat, the latter the carbohydrates, milk sugar (lactose). Certain micro-organisms turn milk sour and precipitate the casein.

Butter results from "churning" milk. The fat collects into one mass, and the protein is left behind with most of the carbohydrates. Here again, bread, deficient in fat, but rich in protein and carbohydrates, is the natural accompaniment.

Aerated Waters are very popular with all classes. These comprise Soda-water, Ginger-beer, Lemonade, etc. They all contain Carbon Dioxide in excess of its ordinary solubility, which is not high. The gas is therefore forced into the water,

previously flavoured, by increasing the pressure to as much as eight or more atmospheres. When this is removed on opening the bottle, the gas escapes, and the liquid appears to boil. A handy way of making soda-water is by the aid of so-called "Sparklets," little steel vessels containing liquid Carbon Dioxide. When fixed in the top of a bottle, they aerate the liquid on perforation of the cover. The gas

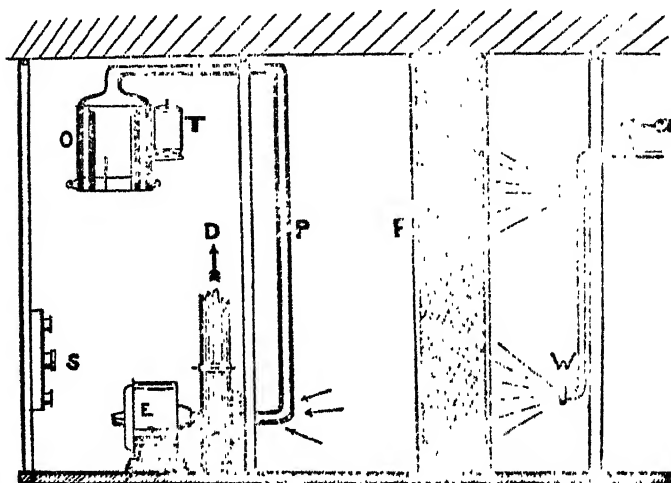


FIG. 110. VENTILATION OF A ROOM BY OZONE
By permission of Messrs. Ozonair, Ltd.

- | | |
|---------------------------|--------------------|
| W Fresh air. | S Switchboard. |
| A Water sprays. | O Ozone generator. |
| F Air filter screen. | P Ozone pipe. |
| M Mixing chamber and fan. | T Transformer. |
| E Electric motor. | D Air discharge. |

escapes and under its own pressure is forced to dissolve in the liquid (Fig. 109).

Welsbach Gas Mantles are familiar to us in the lighting of our homes. This method of illumination was the outcome of investigations by Baron Von Welsbach into the nature of the rare elements Cerium, Lanthanum, etc., found in Monazite sand, which contains Thorium and Cerium, and in other bodies. Taking a piece of cambric and soaking it in a

solution of Thorium Salts with 1 per cent of Cerium, he suspended it in the flame of a Bunsen-burner, obtaining thereby a brilliant light. The proportion of Cerium is very small, but of vital importance, since without it the oxide of thorium used does not become luminous. It is one of those instances in chemistry where the addition of a very small quantity of a particular substance seems to transform entirely the properties of another.

To-day the mantles, which have revolutionized the gas industry, are made from cotton or ramie thread fashioned into the required shape and then dipped into the illuminating mixture. The salts are afterwards burned off with the organic matter of the mantles, and the resultant ash is hardened and varnished.

Another interesting application of Cerium lies in its property of producing sparks. It was found by Baron Welsbach that an alloy of this metal with Iron, or better still, Aluminium and Magnesium could be utilized for the purpose of lighting cigars, cigarettes, and even gas. They can be obtained in tobacconists' shops. The waste products in the mantle industry are used for this purpose.

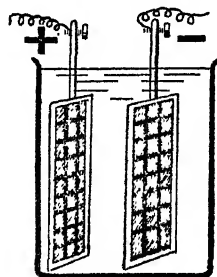


FIG. III. SMALL EXPERIMENTAL ACCUMULATOR

Electrical Accumulators are also employed for lighting purposes. They are extensively used to-day for lighting motor-cars, for household use, in pocket form and in other ways. The action inside these cells is a chemical one, and is a good illustration of the transformation of energy. No electricity is stored up. Take the case of a simple cell. It consists of two lead plates, one of which is coated with Lead Oxide (positive) and the other with Spongy Lead (negative) of a porous nature, immersed in strong Sulphuric Acid in a glass or ebonite case (Fig. III). In order to increase the quantity of the active material and to prevent it from falling out, the plates are cast in the form of grids. The cell is

"charged," as in Electrolysis, by passing a current of electricity through it. The Lead Oxide on the anode (+) is oxidized to Lead Peroxide by the Oxygen ions, while the spongy lead on the cathode (—) is de-oxidized by the Hydrogen ions. When the operation is completed a current of electricity may be obtained, on joining up the circuit, through chemical action. This current continues until the two plates resume their normal condition; thus electrical energy is transformed into chemical, and this again reconverted to electrical by this interesting form of battery.

The beautiful dyes which, as we have seen in a previous chapter (Chap. xxii), are obtained from a very unattractive source, coal-tar, are used for many purposes. Their success-

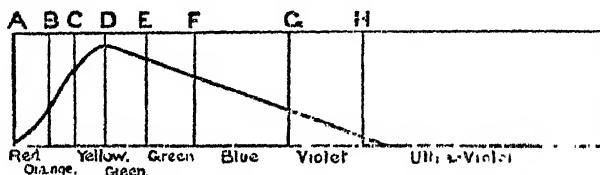


FIG. 112. LUMINOSITY CURVE IN THE SPECTRUM OF WHITE LIGHT

ful employment in modern photographic practice is one of the interesting features of Applied Chemistry to-day.

It is necessary in photographing coloured scenes and objects that all the different colours, as far as possible, should be translated into monochrome in their correct relative value. The ordinary plate is too sensitive to the ultra-violet, violet and blue rays of the spectrum, while the yellow and red rays affect it but little (Fig. 112). Yellows, reds, yellow-greens are depicted too dark, blues and violets too light. Colours are not recorded in terms of their luminosity. For all classes of work, landscapes, portraiture, copying of pictures, flower photography, a truthful representation in monochrome of all the light values cannot be obtained without some form of correction.

Some of the coal-tar dyes such as Eosin, Erythrosin, Cyanin, etc., when incorporated with the emulsion give

sensitiveness to the more luminous parts of the spectrum. Such plates are known as ortho-chromatic (*orthos*, correct; *chroma*, colour, Grk.). They require, however, a compensating yellow screen, since they are still too sensitive to blues and violets.

Such plates, although they give a much better rendering than ordinary plates, cannot be said to be truly ortho-chromatic; cannot, in fact, give an exact colour rendering of general objects since they are comparatively insensitive to the red end of the spectrum. We want a green and red sensitive plate recording all the colours of the spectrum in their correct value. Such plates are called panchromatic (*pan*, all, Grk.). The Kodak Company, who have kindly supplied me with much information on this subject, claim that their Wratten panchromatic plate in conjunction with their standard "K" Filters (K₁, K₂ and K₃) give a perfect rendering of objects with all the colours in their correct relative value in monochrome. And there is no doubt that in this way an excellent correction can be made of the faults to which the ordinary plate is subject. For the proper development of these colour-sensitive plates special "safe-lights" must be used in the dark-room. A green light (Series 3) is recommended. When the light is very faint it appears that the middle of the green is by far the brightest. There is no difficulty in working with this colour.

Judging from the number of light filters prepared from special dyes, particulars of which have been given me by the Kodak Company, there would appear to be a filter for every conceivable purpose. Some are used in purely scientific work as in colour investigation, some in photomicrography to secure contrast with objects like bacteria, etc., previously stained in order to differentiate their structure. Then, too, we find them used as selective filters in Colour Photography, and also for monochromatic work—transmitting special bands of the spectrum. The gain to photography alone from coal-tar dyes is very great.

CHAPTER XXIII

CHEMISTRY AND PLANT LIFE IN FIELD AND GARDEN

THE humblest plant which grows in wayside hedges, the stateliest trees of woods and forests, are living organisms with functions and duties corresponding in many ways to those of animals and human beings. Such functions as growth and the capability of assimilating food and nourishment from outside sources are instances. Even the humblest and minutest plants, tiny one-celled bodies like the *Algæ*, with little differentiation of structure, all perform in their way vegetative and reproductive functions. In all organisms, that mysterious jelly-like substance protoplasm is the living basis of the cells. It is composed of the elements Carbon, Oxygen, Nitrogen, etc., and is highly complex in its nature, chemically corresponding to albumen or white of egg. It is a soft mass and varies in consistency according to the amount of water present, and although we cannot say that to plants belongs the same capacity of movement such as we see in higher types of life, yet even in them there are to be observed, if we carefully look for them, certain powers of movement often minute and subtle.

The circulation of protoplasm in cells, the response of leaves and tendrils to natural and artificial stimulation such as we see in the clover, the sundew and the common pea are instances ; so, too, in flowers which open and close their petals at stated times.

Speaking generally, plants are organisms which are unable to change their positions, and thus we find them exhibiting marvellous powers of adaptation in order that they may correspond to their environment. And this especially in the case with regard to food and nourishment.

In animals the power of locomotion is very great ; they can wander whither they will in search of food, but plants are fixed. Herein lies the difference. From whence are they to obtain their food supplies, how best procure their share of light and air ? Such questions as these are of vital importance to the plant itself, and of fascinating interest to lovers of plant life.

From whence, then, does a plant obtain its food, those inorganic raw materials which a wonderful mechanism reduces to simpler forms ? From the air, from water and from the soil. These are the sources from which the plant builds up its wonderful structure, making use of such elements as Carbon, Hydrogen, Oxygen, Nitrogen and others. As we might suppose, the plant assimilates its nourishment in a way different from that of animals or human beings. Yet, as we shall see later, there are some plants which, by reason of certain modifications of form, obtain their food from living nitrogenous matter, and actually digest it. They secrete a form of gastric juice similar to that found in the human stomach. Such plants are known as Carnivorous.

Let us look now at the three sources of food we have mentioned, and note the wonderful way in which a plant manufactures, as it were, its organic food in the living laboratory by chemical change.

Unlike the members of the Animal Kingdom, the plant can only assimilate its food either in the state of solution or in a gaseous form. It cannot take solid food. The mechanism it employs is one of the marvels of plant life. We will take the air as the first source of food and examine it somewhat in detail.

It has been stated in a previous chapter (Chap. VI) that the air we breathe has for one of its ingredients a small quantity of Carbon Dioxide-gas, and it is this gas which is the source of all the solid material of the plant. The mechanism whereby the gas is decomposed into its constituents, Carbon and Oxygen (for the gas must be split up before the plant can make use of it), lies in the leaves. They take this gas, poisonous to all animal life, and decomposing it take up the

Carbon and return the Oxygen to the air. But this only in daylight ; and it is the sun with its beneficent rays which is the chief agent governing the action. It supplies the Energy by which the leaves perform their wonderful task.

A leaf highly magnified will disclose not only a large number of cells but also thousands of little open mouths called Stomata, provided with movable lips. Through these

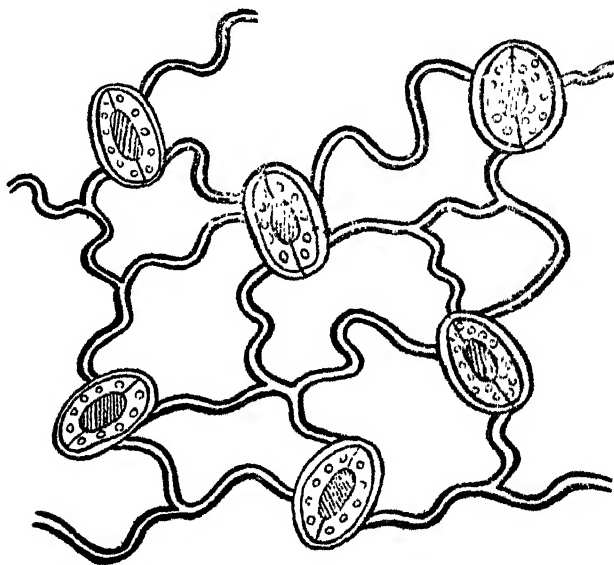


FIG. 113. UNDER SURFACE OF A LEAF, SHOWING STOMATA
Highly magnified.

the air in the daylight hours circulates freely, carrying with it the Carbon Dioxide into the cellular divisions (Fig. 113).

Now, besides the protoplasm which is the constituent of each individual cell, there is one important substance whose function it is to utilise the light rays and turn them into food. This substance is Chlorophyll, a green colouring matter present in the cells. For the most part it consists of small particles or grains, and the green of most plants is due to its presence—without it a plant cannot obtain food

from purely inorganic compounds: Non-green organisms like the fungi, mildew and others, find their food in other ways, as for instance, from dead organic matter.

If a solution of Chlorophyll in alcohol be examined by the aid of the Spectroscope, there will be seen, in place of the red region of the ordinary spectrum, a dark band with paler bands in the green and yellow regions. All the rest of the spectrum is blotted out in the blue and violet—or nearly so. This dark band is called the Absorption Spectrum of Chlorophyll (Fig. 114).

Now, the same action goes on in the living cell. Certain rays are absorbed by the plant, and the little green grains provide the energy required for the formation of food when the light strikes them. It is a wonderful provision of Nature, and but imperfectly understood. In the laboratory the

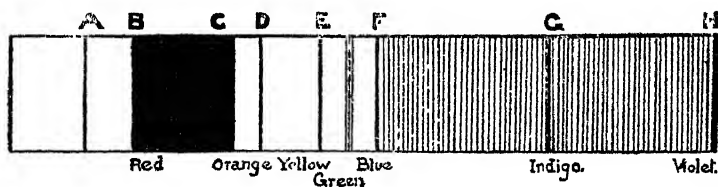


FIG. 114. ABSORPTION SPECTRUM OF CHLOROPHYLL

splitting up of gases into their constituent parts is often a hard and laborious business. Here we have the plant performing the task with seeming ease. Chlorophyll is a magician working chemical changes in a magic way.

Before looking at the materials which are the output of the living laboratory of a leaf, the result of the transformation of a gaseous body into organic compounds like sugar, starch, etc., a word or two must be said about the actual leaves themselves. How well they play their part in this magic Alchemy!

Look at the shapes of leaves and their positions on a tree or plant. Some, it will be noticed, are flat and broad, so as to catch as much of the sunlight as possible. Some are cleverly arranged so as to avoid overlapping. This is seen in the

ivy. Some stand out from the stems horizontally all round, others shoot up narrow and long. Some are divided up into a number of leaflets such as we see in ferns.

All spread themselves out as best they can with the one great object in view—to catch as much as possible their share of light and air in order to fulfil their natural functions. The food of a plant manufactured from the air consists of Carbohydrates (compounds of carbon, hydrogen and oxygen) for the most part. Some of this is conveyed to the stem and roots in a soluble form. Some of it is converted at once by the leaves into starch for immediate use (Fig. 115).

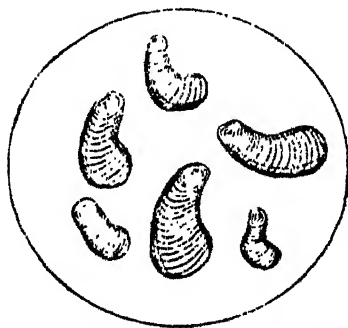


FIG. 115. GRAINS OF STARCH (POTATO)
Highly magnified.

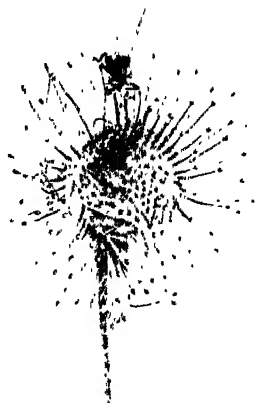
This starch is again transformed into another kind of sugar (malt sugar) by the action of a body called Diastase. This is a ferment corresponding to another ferment called an Enzyme, which is the main constituent of the digestive secretions in the human body. If an extract of malt is produced by germinating barley, we get Diastase formed which is able to convert starch into sugar, as in the process for making beer. An Enzyme and Diastase are therefore similar in their chemical properties.

Each part of a plant has its own particular functions—the stem, the branches, the leaves. Not all the food is used at once, some is stored up to undergo further transformation. This forms a kind of “reserve material.” We see it in such

A



B



C



D



A LIVING FLY-TRAP.

A.—General view of the Sun-dew growing in its swampy home.

C.—The tentacles closing over the unfortunate captive.

B.—Caught !

D.—The leaf closed down, thus completely imprisoning the fly. The Sun-dew begins its meal.

vegetables as potatoes and artichokes, also in the rhizomes of ferns, in bulbs and buds and in roots like beet and carrots. The chemical action involving the extraction of nourishment from the air goes on chiefly in daylight. In darkness Chlorophyll becomes less active, and unable to exercise its functions. No assimilation of food takes place. If a plant be kept in the dark, the leaves soon become pale and colourless, and the formation of starch is reduced to a minimum. The whole plant becomes sickly and "leggy." It is a ghost of its former self.

The absence of light, however, enables us more particularly to examine the Respiration of a plant, a function common to all forms of life. By day the action is somewhat masked.

At night the plant, contrary to its mode of action by day, is always removing Oxygen from the air and returning Carbon Dioxide to it. By day plants purify the air, by night they tend to render the atmosphere impure for animal life. But the balance is in favour of the former, since more Carbon Dioxide is removed by day than Oxygen by night. Moreover, there is always a certain amount of free Oxygen returned to the air in the daylight hours.

In these functions which we have outlined, part of the Energy which results from the chemical action is expended in building up the organic substances of the plant, part is transformed into Heat. In this connection some interesting facts have been observed. The plant, like ourselves, is always burning up Carbon, and if we examine a plant, especially at the flowering period, we shall find heat evolved.

The phenomenon has been observed in the common Arum (Lords and Ladies). Inside the spathe, a quite considerable degree of heat has been measured. Other plants also exhibit the same characteristic. Various Fungi have been found to be sensibly warmer than the outside air. This is not surprising considering the rapidity of the chemical changes which take place in organisms so liable to quick decay.

A certain amount of water is given off by the Stomata of a plant. Often leaves exhale so much that it collects

in little drops at their points. If the action be excessive (as on a hot day) the plant wilts and droops. A provision of Nature in tropical countries to reduce the area exposed to the sun's rays is seen, for instance, in the Eucalyptus. The leaves hang edgeways to the sun. Water is a source of food. Plants obtain it by means of their roots. Their special function is to absorb the various salts which exist in the soil and which are soluble in water. A plant, for instance, requires Nitrogen which is so abundant in atmospheric air. Plants do not take it from this source; they assimilate it in the form of Nitrates or compounds of Ammonia. Sulphur

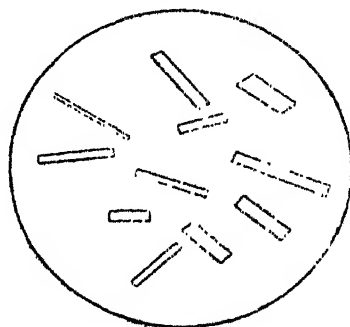


FIG. 116. RAPHAIDES (ONIONS)
Highly magnified.

is absorbed in the form of Sulphates; Phosphorus in Phosphates; Hydrogen from the decomposition of water; Iron, too, in small amounts to support the green colouring matter; Calcium and other elements all occur in the stems and tissues. Those beautiful crystals called Raphides, seen under the microscope in cells of the hyacinth, are mostly forms of Oxalate or Sulphate of Lime. They are long and needle-like. In the Onion they are prismatic (Fig. 116). The Root of a plant is one of its most important organs. The tip, highly magnified, consists of a number of cells with a delicate sheath at the extreme end. And it is this part of the root which enables a plant to obtain food from water and soil.

Then there are those wonderful root-hairs, so fine, so delicate, which clothe the growing tip with a velvet surface, slender one-celled filaments or tubes. They absorb all those nutritious materials which are so essential to the life of the plant. These they suck up through the membrane and outer walls of the tubes.

The method by which plants obtain their food as seen above, does not apply in any marked degree to certain curious plants which have very little Chlorophyll, that magic agent, in their cells. They are not typical of the great bulk of plants, since they eke out a living (often a good one) at the expense of some unlucky neighbour.

Certain parasites (as they are called) like the Dodder (*Cuscuta*) with its long red filaments, the Broomrape (*Orabanche*) and the Mistletoe (*Viscum album*) with its dull yellow-green leaves, are examples. All these manage to live on some luckless plant, their host, from whom they obtain their nitrogenous food. Sometimes, as in the case of the Dodder, they eventually cause its ruin.

Those curious plants, which are called Carnivorous, are especially interesting since they obtain all the Nitrogen they require from *living* matter, usually little insects.

The Sundew (*Drosera*) is an example. It is common in boggy places. There its little cluster of red leaves covered with glandular hairs or tentacles show up conspicuously against the green herbage of moss and short grass. The glands secrete a viscous transparent fluid which glistens in the sun and gives the plant its name. But they are a terrible trap to any unlucky fly which happens to alight on them. It is at once held fast and imprisoned, and the more it struggles, the worse it is. Then a wonderful thing happens. If carefully watched the tentacles will be seen to gradually bend inwards over the fly, eventually closing over it completely. At the same time the action carries the fly down to the centre of the leaf, and all the time a copious secretion is poured over the unlucky captive. The Sundew is beginning its meal. Bathed in the secretion, the little fly is soon suffocated and its struggles come to an end. The whole

leaf commences to curl over and the process of digestion begins. All the nitrogenous portion of the wretched fly within that terrible grip is absorbed, for digestion it really is. The leaf is a living stomach, secreting an acid ferment similar to that in human beings. It is entirely a chemical process, and a very interesting one.

When all the soluble matter has been absorbed, the leaf slowly uncurls again and resumes its normal shape. The Sundew sets up its trap once more, and baits it with bright shining drops of what seems sweet honey. It is ready for another meal! The extraordinary thing about the Sundew is its power of discriminating between nitrogenous and other matter. The tentacles exhibit no response to glass, paper, etc. A tiny speck of boiled cabbage, white of egg, a drop of milk, at once stimulate the glands. The story of this remarkable plant is the story of a very wise provision of Nature. The Sundew cannot obtain much Nitrogen from the watery soil which is its habitat. It adopts the rôle of a living trap, and plays its part well.

A word or two must be said about water-plants. Here, of course, the conditions which obtain in air do not operate. Such light as filters through the water layers is dimmed and its action diminished. However, there is a certain amount of Carbon Dioxide dissolved which supplies the leaves.

These leaves are often very much divided, thus offering a larger surface for absorbing the gas, The same with regard to respiration. Some aquatic plants possess two types of leaves, floating and submerged. The former are round and large. They get plenty of sun and air. The latter are often finely divided, thus offering increased surface for absorbing the gas. Some aquatics in stagnant water risk suffocation through lack of Oxygen. In all a considerable modification is seen in the action of light in proportion to the depth to which the plants are submerged. Gradually the green of the Chlorophyll grains is masked by brown and red pigments. Then we come to plants like the Algæ and Sea-weeds, exhibiting only those colours which are capable of absorbing the modified rays of light.

In all cases of plant life there is a continuous cycle of operations taking place. The plant takes Carbon from the air by day, and forms organic compounds which constitute the food of animals and men. It gives out Oxygen which the animal absorbs. At night the reverse obtains: the plant absorbs Oxygen and gives back a certain amount of Carbon Dioxide to the air. Finally, on decomposition, there results both from plants and animals Carbon Dioxide, water and inorganic salts. A cycle from inorganic to organic and vice versa.

The Soil is the last source of food. Upon its nature the life of a plant greatly depends. All who are gardeners are aware of this. From this source comes the supply of Nitrogen in the form of soluble salts. A lump of soil, if carefully examined, will be found to consist of little particles of rock, the result of the weathering or breaking up of various rock systems by chemical action, frost and other agents. Water in which Carbon Dioxide is dissolved attacks not only granite but also limestone and chalk formations, giving rise to deposits of clay, sand, etc. Soil may be a mixture of any or all of these ingredients in varying proportions. But one very important constituent must also be present—this is Humus. It consists of decayed vegetable matter which eventually is converted into water, Carbon Dioxide and various soluble salts such as Nitrates, Phosphates and compounds of Nitrogen and Ammonia.

There are other factors to be taken into consideration. The amount of water in the soil, its position with regard to sun and air, the aeration of the little particles, so that plenty of Oxygen may reach the roots—all these are important. If a particular soil is deficient in those ingredients which make for healthy plant life, use must be made of artificial manures. The chemist comes to the rescue of the unfortunate gardener or farmer. He directs Nitrates, or some form of Potash or Phosphates to be incorporated with the deficient soil. From agricultural laboratories are sent tons of cunningly devised manures for every purpose. Potash is useful for the formation of fruit, in the form of

Sulphate of Potash, Kainit, a cheaper form, and wood ashes. Nitrates assist in leaf, cell and stem formation. The bright healthy green of leaves is due to their influence. Nitrates are applied in the form of Nitrate of Potash, Nitrate of Soda, Nitrolim, a modern product, Soot and Sulphate of Ammonia. Phosphates are useful for the development of flowers and seeds. They are applied in the form of Phosphates of Lime, Superphosphates and Basic Slag. This latter has proved most useful in agriculture. Lime, too, is valuable from a manurial and mechanical point of view. It sets free Potash and helps to decompose organic matter. It also neutralizes sour soil. It is applied in the form of chalk, ground lime, etc.

All these artificial manures, however, do not take the place of good farm-yard manure. They are useful when ordinary manure is difficult to obtain.

A system of Green Manuring has been successfully adopted of late years. Leguminous plants like Vetches are sown broadcast and the resultant crop dug in. Such plants (including also peas, beans) are able to fix atmospheric Nitrogen and store it up in those curious little nodules or swellings seen on the roots. When dug into the soil, a considerable increase of nitrogenous material is obtained.

Since different plants exhaust the soil in time, each extracting particular salts from it, it is obvious that the same crop should not be grown in one plot of ground continuously. Thus peas and beans extract a good deal of Nitrogen from the air, and if they follow such a crop as turnips they enrich the soil once more. For turnips, swedes, etc., exhaust the soil considerably. This is known as the Rotation of Crops. In the application of the principle lies the secret of good farming and good gardening.

It has been remarked above that Humus is one of the constituents of all good soils. Now its conversion into organic matter is enormously assisted by countless numbers of minute microbes known as Bacteria. Beneath the quiet surface of our gardens and fields, infinite swarms of these little entities are for ever effecting chemical changes in the

decaying vegetable matter. They help to replenish the soil with Nitrates and Ammonia. To the roots of peas and beans they cling, swarming in the nodules already mentioned. Millions are contained in a pinch of earth. They multiply indefinitely, and are some of the greatest benefactors of the human race.

Of late years an attempt has been made to utilise the remarkable properties of Radium in plant culture. Experiments have been made both in this country and in France. The results so far are unsatisfactory. Electricity, however, has yielded good results, but its application has not advanced beyond the experimental stage.

The Sterilisation of Soil for the purpose of killing harmful organisms as well as the destruction of those Bacteria which have been found to exercise an injurious influence, is extensively adopted to-day. In a report on the partial sterilisation of soils at Rothamsted, it appears that this is carried out either by heating the soil or by chemical means. In the latter case the method consists in adding to the soil some poison strong enough to kill all harmful organisms. The results in both cases lead to an increase in the production of Ammonia and Nitrates, and the destruction of many poisonous organisms and pests detrimental to the bacteria which are found to be so beneficial. The soil, too, appears to be all the better for the treatment which it receives. The plants get more nitrogenous food, and a healthier medium in which to live. Different soils were subjected to experiments carefully carried out, and the general result was to confirm the earlier work carried out merely in the laboratory with pot plants. Partial sterilisation in a nursery carried out on a large scale proved the commercial value of the process. There is no doubt that useful crops of increased yield can be obtained in this way. Diseased or "sick" soils showing low bacterial efficiency are much improved by the treatment.

Before concluding this chapter we must draw attention to the new method of converting straw into a useful fertiliser by the aid of certain bacteria and bacilli. Excellent manure

for agricultural purposes is thus obtained from material which is often regarded as valueless. Since horse manure is getting scarcer every year, the new product, which illustrates the beneficent results of modern research in a striking way, comes before us at a very opportune time.

Close upon this discovery comes the announcement that a valuable gas for lighting and other purposes can be made from all kinds of waste nitrogenous matter which may be found in large quantities in farm and garden. Once more the chemist assumes his accustomed rôle of benefactor to the world at large.

CHAPTER XXIV

SOME ASPECTS OF INDUSTRIAL AND APPLIED CHEMISTRY

WHEN a fire is burning brightly in a grate, little jets of smoke are often seen issuing forth from the coals. Sometimes they catch fire and burn with a bright though smoky flame. What happens in the grate is very much like what takes place in the manufacture of gas for illuminating purposes, with this difference. The coal is heated in closed retorts so that all the products of its destructive distillation, gaseous liquid and solid, are conserved. The little jets to which we have alluded are impure gas. Let us briefly see how the purified gas which we use every day is made.

The method, shortly outlined, is as follows : The coal is heated in clay retorts, and the resultant gases pass into a long horizontal cylinder containing water, in which the tar and other watery condensed matter collects—ammoniacal liquor as it is called—to flow finally into a well from whence it may be collected. The gases themselves pass on into refrigerating condensers consisting of curved pipes, where the last portions of tar and liquor are condensed, and from the bottom of which they return to the well. The gaseous products pass on into "scrubbers" or vessels containing coke moistened with sprays of water. Here the gases are washed and then they pass into the "purifiers" in order to rid them of Sulphuretted Hydrogen, Carbon Bisulphide and Carbon Dioxide. These vessels contain Lime or Oxide of Iron, and the impurities which play no part in illumination and are deleterious to health are thereby removed. The gases (for the final product does not consist of one only) pass on to the gasometers from which, under a given pressure,

they issue forth into the public mains. In the annexed diagram (Fig. 117) part of the process is depicted.

A quantity of coke is left behind in the retorts, which is a valuable by-product. The tar, too, is of great value. It is the raw material which the chemist takes and converts by subtle chemical changes into substances which, for the most part, do not suggest so unlikely an origin. Explosives of terrific violence, dyes of gorgeous and bewitching colours, competing with Nature herself in the brightness of their hues; elegant preparations; patent drugs of all kinds, the last word in pharmacy; perfumes diffusing their fragrance

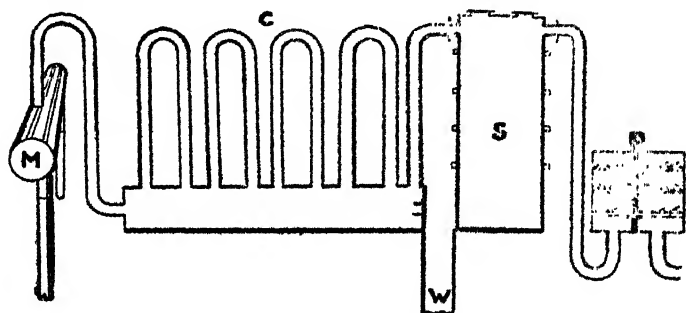


FIG. 117. MANUFACTURE OF COAL GAS

M Hydraulic main.

W Tar well.

C Condensers.

S Scrubber.

P Purifier.

into the air; essences and sweet-smelling extracts, delicate and distinctive; and a substance like Saccharin, a derivative of Toluene, which possesses so sweet a taste that it far surpasses cane sugar in this respect.

All have their origin in that dark repulsive mixture which collects in the wells. The ammoniacal liquor, freed from the tar, is a valuable by-product. The supply of manure in these days is unequal to the demand for agricultural purposes. The liquor contains Nitrogen, and in the form of Ammonium Sulphate, into which it is ultimately converted, it is largely used by the agriculturist and gardener for their crops. In these days when the horse is a decreasing factor

in our life, and the supply of stable manure correspondingly scarce, we have to fall back more and more upon artificial substitutes. Then, too, we must remember that the natural sources of nitrogenous manures—guano and Chilian nitrate—are also failing alarmingly. We shall review in the next chapter the means whereby it is hoped to combat this deficit. The welfare of agriculture, and indeed every form of cultivation, is intimately bound up with this important question.

It is estimated that from one ton of coal 10,000 to 11,000 cubic feet of gas can be obtained, over 100 lb of tar, and from 20 to 25 lb. of Ammonium Sulphate. The actual gases present in the mains are Hydrogen (about 50 per cent) with Methane or light Carburetted Hydrogen (about 35 per cent), and small quantities of Olefiant Gas, Carbon Monoxide, Nitrogen, Carbon Dioxide and a trace of Sulphuretted Hydrogen and some Hydrocarbons in very small quantity. Olefiant Gas contributes largely to the luminosity, Methane and Hydrogen to the heating quantities.

In order to get the value of the illumination of gas, issuing as it does from the burner at the rate of about five cubic feet per hour, it is necessary to compare it with some standard source of light. This is a sperm candle burning at the rate of one hundred and twenty grammes per hour. The intensity of light varies inversely as the square of the distance between a screen and the source of radiation. Hence if equal shadows are cast by a gas flame (Fig. 118) at a distance of fifteen feet and a candle at five feet, the gas would be said to have an illuminating power of nine candles.

Explosives, used so much in the late war, in their modern forms are sinister examples of Applied Chemistry. The number of different explosive materials is so great that a full list of them would probably surprise the general reader. They range from Gunpowder, the oldest of them, Gun-cotton, Dynamite and others, to more modern compounds derived from coal-tar constituents, and those very unstable substances like Nitrogen Iodide, which are quite unfit for

use, since they explode with great violence at the slightest touch. All contain great stores of Energy in potential form. When disruptive action takes place, and they are dissociated into gaseous products, these occupy a volume considerably greater than that of the original material, and at the same time great heat is evolved. The potential energy appears in kinetic form, part of it assuming the form of heat and part mechanical work with results which we all know. At the same time we must not associate explosions entirely with destruction of life and property. They occur every moment in the cylinders of a motor-car as it travels along the road, in all kinds of stationary gas

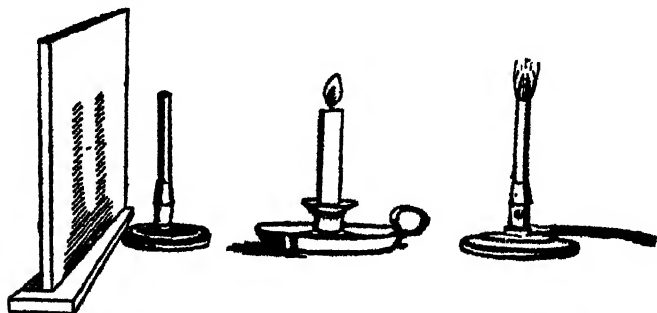


FIG. 118. COMPARING THE ILLUMINATING POWERS OF A CANDLE AND A GAS FLAME.

engines, and we all of us know their use in quarries and elsewhere. But owing to the disastrous effects of explosions in mines, with compressed gases, and in other ways, our minds are apt to be led away from contemplating their purely utilitarian purposes.

Gunpowder is not so much used now as formerly. We generally attribute the invention of this mixture of Nitre (Potassium Nitrate), Sulphur and Carbon to Roger Bacon (Chap. 1), born in 1214. On explosion the gases evolved are Carbon Dioxide, Carbon Monoxide and Nitrogen. But there are a number of objectionable solids produced which cause an undue amount of smoke, and in modern guns this seriously detracts from the use of gunpowder as a propellant.

Gun-cotton is a useful explosive substance. We have, in another chapter, learned something about cellulose, the chief constituent of vegetable tissue. Cotton in its purest form is a good example. So also cotton wool, cotton fibre. Now, if we take cotton wool and soak it in a mixture of strong Nitric and Sulphuric Acids, and then wash and dry it, we get a substance technically known as Gun-cotton, which is used as an explosive substitute for gunpowder in modern propellants. Since the products of explosion are gaseous, there is less smoke and less corrosion. Their volume is double that of the explosive products of gunpowder, and gun-cotton is therefore a very powerful and dangerous substance. Yet a small portion may be placed on the palm of the hand and ignited, when it will burn rapidly away in a harmless manner. But suppose that we alter the conditions under which it is ignited, and cause it to burn in an enclosed space, the result is very different! The substance is converted quickly and suddenly into its gaseous products with extreme violence. It is usual, in practice, to explode it by means of a detonating fuse in contact with it. This fuse contains Fulminate of Mercury, another highly explosive material. But there is this further to be observed. Even if a detonator be not actually in contact with the material, the concussion of the surrounding air is sufficient to cause it to break up with explosive violence.

The lower nitrates of cellulose, for we must remember that this substance is able to form salts with Nitric Acid—Ethereal Salts—are soluble in a mixture of Ether and Alcohol, forming a solution of Collodion, a transparent liquid which on evaporation from any surface leaves a thin film behind, which finds its application in surgery and photography.

Nitroglycerine is a very powerful explosive. When Soap is made by boiling fat with Caustic Soda, an important by-product is obtained in the form of a thick, colourless and sweet liquid which mixes easily with water. This is Glycerine or Glycerol, which is a constituent of most fats. Thus butter consists of the ethereal salts of this substance with

various acids such as Palmitic, Stearic, Butyric, etc. To this latter it owes its flavour.

Glycerine is an alcohol, and with Nitric Acid forms the ethereal salt (Chap. xx) Nitroglycerine, an important and powerful explosive. It is an almost colourless liquid which burns quite quietly unless it is heated strongly when it explodes, as it does also by concussion. An enormous volume (some ten thousand times that of the original material, it is estimated) of gas, mostly Carbon Dioxide and Nitrogen, is evolved with great heat, so that it is a very formidable explosive indeed. In practice it is usual to add a little Sulphuric Acid to the Nitric to increase the yield of explosive.

A mixture of gun-cotton and nitroglycerine together with some acetone (a colourless liquid with a pleasant ethereal odour derived from acetates) to act as a solvent, forms a gelatinous mass which is used for blasting purposes. When on removal of all the solvent the mass is dried and cut into cord-like lengths it is known as Cordite, which forms the basis of all smokeless powders.

Dynamite is closely connected with Nitroglycerine. In order to remove some of the defects of Nitroglycerine (its too concentrated action, its condition as a liquid, etc.), a certain proportion of some porous incombustible substance is mixed with it. One is an infusorial earth called Kieselgur. This is a siliceous powder formed from minute shells of diatoms and other primitive plants and animals. The mixture is easier to handle than the original material, it is safer in use, and more easily transported. It is known as Dynamite (*dunamis*, power, Grk.).

Lyddite is another form of Picric Acid. If we treat Carbolic Acid (Phenol), which is one of the constituents of coal-tar, with Nitric Acid, a yellow crystalline substance with a bitter taste is obtained. This is Picric Acid, which is not only used as a dye for wool and silk, but also as an explosive under the name of Lyddite. It forms salts with Potassium and Ammonia, which are also very unstable bodies, and are liable to explode spontaneously.

Trinitrotoluene (T.N.T.) is one of the newer explosives,

and was extensively used by the Germans and also by us in the late war for high-explosive shells, mines and torpedoes. Toluene is one of the Benzene series of Hydrocarbons obtained from coal-tar. With Nitric Acid it forms certain nitro-compounds, of which T.N.T. is the famous explosive.

If we take Benzene, also a coal-tar product, and act on it with Nitric Acid, we get, first, Nitro-benzene, an aromatic compound, by substituting Nitrogen Tetroxide for one atom of Hydrogen. By a double substitution we get Dinitro-benzene, which is another explosive body. From Benzene we get Aniline, which is the source of a large number of dyes of beautiful colours. Thus a perfumed body, a high explosive and a substance which is the starting-point for tints and hues of every description are closely allied to one another.

Perfumes and Essences appeal to everybody. If a piece of lemon or orange peel be bruised, a number of minute drops of a fragrant oil will be seen. This contains within itself the concentrated smell and taste of the original fruit in a high degree. We call the substance the essential oil of lemon or orange as the case may be. Other examples are the oils of Lavender, Caraway, Rose (Otto of Rose), Orange Flower (Neroli), Almond, Rosemary, Jasmine and others.

In order to extract these volatile oils, several methods are adopted. Distillation with water is a common process much used in France, that home of perfumes. The oil passes over with the steam, and can be collected from the water on condensation; being lighter it floats on the surface (Fig. 119).

Another method is to macerate the flowers in highly clarified lard or other material in a hot liquid state. This takes up the perfume. The fat is then added to rectified spirit and distilled off. By whichever process the oils are obtained, they are either used as concentrated essences, incorporated with spirit, or added in minute quantities to distilled water, forming lavender water, orange water and the like. Sometimes different perfumes are blended together to produce such distinctive scents of rare quality as Eau de

Some Aspects of Industrial

Cologne and others. What oils are used and in what proportions they are blended together are often trade secrets jealously kept. As far as Eau de Cologne is concerned, we can picture to ourselves, probably with some truth, such fragrant ingredients as the essences of bergamot, citron, orange flowers, roses, lavender and others, as forming the main constituents of that delightful scent.

Many of the volatile oils are closely related to turpentine, or rather to one of the Terpenes, a Hydrocarbon in fact. And although they share this common formula between them, they often exhibit quite distinct properties. They

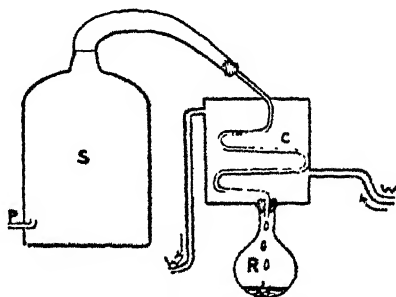


FIG. 119. EXTRACTION OF ESSENTIAL OILS

S Still.

P Steam pipe.

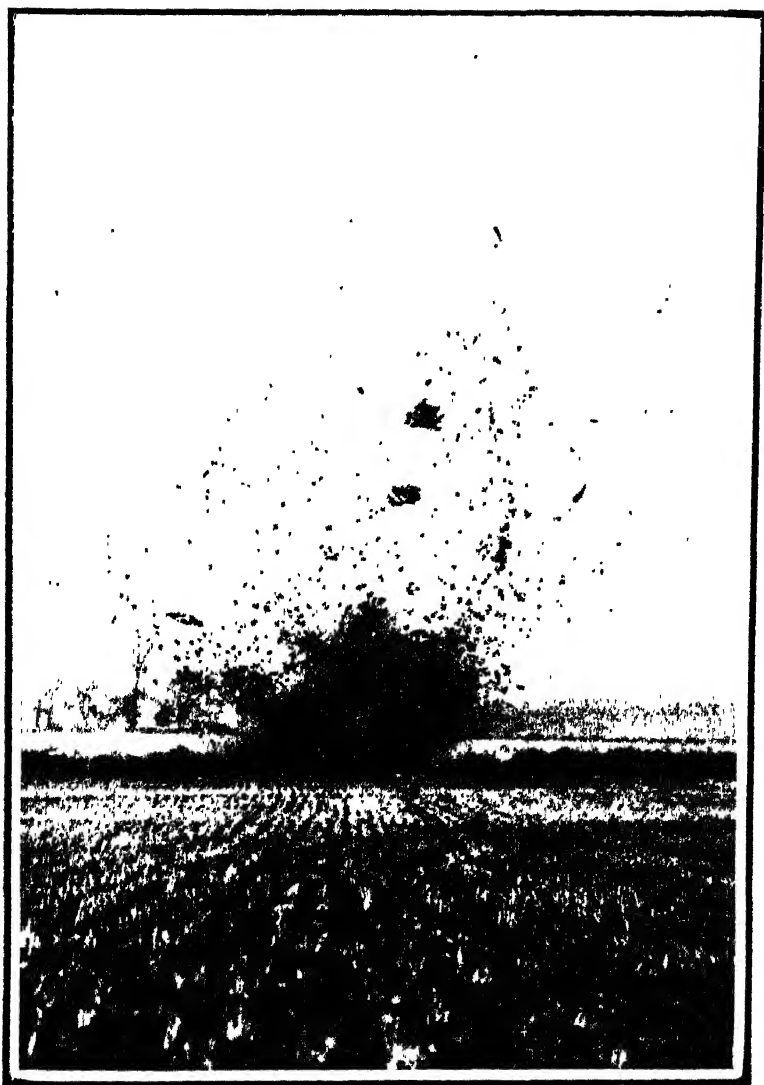
R Receiver.

C Condenser.

WW Stream of cold water.

are, in chemical language, Isomers of the Terpene, a curious property noticed in a previous chapter (XXI). Many of the Terpenes themselves are aromatic bodies; Turpentine, or its oil, obtained from the *Pinus Nigra*, *Pinus Australis*, Terebene from *Pinus Maritima*, used for scenting soap, the Camphors, the common variety, and Borneo Camphor or Borneol, which are compounds of Carbon, Hydrogen and Oxygen, Menthol, and others.

Camphor is a very well-known aromatic substance. The ordinary variety is obtained from the *Laurus Camphora* of China and Japan. It is obtained by distilling the wood in water and submitting the crude product to rectification,



Sport and General]

[Press Agency.

EXPLOSIVES IN TIME OF PEACE.

Part of a hedge with tree and bushes torn up and lifted sky-high by the devastating energy of Dynamite.

when it assumes the appearance of a fragrant crystalline white substance with which we are all familiar. Borneol is obtained from the *Dryobalanops Camphora*. It can be converted into the ordinary form by oxidation.

Balsams and Resins are fragrant bodies which in the case of Resin (*Colophony*), Mastic, Copal, are obtained from the Terpenes. Balsam of Peru and Tolu contain Gum Benzoin and an ethereal salt, Styryl Cinnamate, to which they owe their sweet-smelling properties. When they are burnt they evolve volatile oils and odoriferous vapours, the result of decomposition. These diffuse into the surrounding air in all directions. The characteristic properties of Incense are due to these aromatic substances.

There is probably no flavouring so universally esteemed in cooking and confectionery as that well known body, Vanilla, obtained from the pods of *Vanilla Aromatica*, a plant of tropical America. The active constituent is Vanillin, and its fragrance is due to an essential oil.

Coumarin is allied to the resins, and is the active principle of the Tonka Bean (*Dipterix odorata*). It has the smell of clover or new-mown hay, and is present in small quantities in sweet-scented Vernal Grass, in Melilot and in Sweet Woodruff.

The chemist has been busy for many a year, busy in his laboratory producing artificial or synthetic bodies, drugs and various pharmaceutical products, dyes of every hue, artificial foods and other organic substances. We need not therefore be surprised that he has extended his efforts into other directions, has striven in fact to wrest from Nature herself those secrets so closely guarded in plant and flower, the secrets of their perfumes and fragrant essences.

Bitter almonds when crushed yield an oil of characteristic odour much used in cooking and confectionery. The chemist takes coal-tar as a starting point and forms Benzoic Aldehyde, which is the active principle of the oil. From the same source Benzene is obtained, treated with Nitric Acid, and we have Nitro-benzene, which is another very good substitute known as Essence of Mirbane. And from Phenol or Carbolic

Acid artificial Coumarin is obtained. Camphor is now a synthetic product, made in the laboratory from Pinene (Oil of Turpentine) by treatment with Hydrochloric Acid. A white product, Bornyl Chloride, of crystalline structure is the artificial substance.

The popularity of Vanilla is such that the demand exceeds the supply. Accordingly the active principle of Oil of Cloves, Eugenol, is taken, and synthetic Vanilla obtained in larger quantities.

Many flowers have yielded up their secrets. Thus Heliotrope, used in perfumery, is made from Piperonal, which is related to Pepper—an incongruous association! Violets with their sweet odour appeal to all. The chemist takes Orris root and turns out an active substance, Ionone, which is an excellent substitute. In soaps, scents, sachets, the well known odour pervades them all, almost *ad nauseam*.

Lily of the Valley is another pleasant perfume. It is obtained from Terpineol, a derivative of oil of turpentine. From Phosgene, one of the deadly gases employed in the late war, comes a scent rivalling that of the violet. From poison-gas to sweetest of perfumes in my lady's boudoir—what a contrast!

Sweets, especially the cheaper varieties, are flavoured with essences which recall those of apples, pears, pine-apples and other fruits. Thus, the ethereal salt of Butyric Acid (contained in butter), Ethyl Butyrate, resembles Pine-apple, Amyl-acetate the odour of Jargonelle pears, and Amyl-valerianate the perfume of apples.

Another ethereal salt or Ester, Methyl-salicylate, is responsible for the artificial production of the active basis of Oil of Wintergreen (*Gaultheria procumbens*). Thus, the synthetic chemist is prepared to give us all kinds of subtle perfumes and odours, from Otto of Rose to the alluring fragrance which is wafted to us from our garden flowers, Jasmine, Hyacinth and others, as well as from those humbler plants which are to be found in many a field and hedgerow.

The volatile basis of wines of all descriptions to which they

owe their characteristic "bouquet" and flavour is imitated by a number of synthetic products which, unknown to the hapless buyer, are largely responsible for the sale of these inferior competitors of the true juice of the grape. And the same applies to Cognac, Rum, Whisky, Cider and other beverages. The disaster to the human economy is often great.

If onions and garlic were to fail, the chemist has a substitute in Allyl Sulphide, which, taking its name from *Allium*, the generic term of the onion tribe of plants, is a very close imitation.

By a careful selection of certain essential oils, together with small quantities of the active basis, Musk, Ambergris, etc., can be counterfeited. If the age in which we live be "artificial," the different artificial products—drugs, foods, scents, etc., are decidedly contributory to this state.

The myriad colours of every hue which give us so much æsthetic enjoyment are largely synthetic products derived from coal-tar materials, and they are examples of Applied Chemistry in one of its most attractive and useful forms. Amongst natural dyes, Indigo is one of the most important. It is also one of the oldest. It is obtained from the Indian plant *Indigofera Tinctoria* by treatment with water, fermentation, and the formation of an insoluble blue product which is washed, pressed, dried and sent into the market. Now, Indigo-blue, which is the basis of the colour, can be made artificially to-day either from Anthranilic Acid obtained from Naphthalene, one of the coal-tar products, or from Nitrobenzene and Aniline. Another vegetable dye is Woad or Madder, with which our forefathers used to dye their skins in time of war. The active principle in it is Alizarin, and the plant itself is *Rubia Tinctorum* and a variety called *Rubia Peregrina*, found in some parts of Britain. An enormous quantity of this colouring matter was used in the old days. Then came the isolation of Alizarin as the basis of the dye, and the subsequent discovery by Graebe and Liebermann that Anthracene, one of the coal-tar hydrocarbons, and formerly thought to be of little value, could by

chemical synthesis be converted into Alizarin. Thus Anthracene took a high position among the coal-tar products, and Madder passed into comparative disuse, though it is still cultivated to some small extent in the eastern counties. An insignificant by-product revolutionised the entire dye industry. The first colouring matter obtained from coal-tar was Mauve, produced by Perkin from Aniline. This he accomplished by a process of oxidation with Di-chromate of Potash. Subsequently it was found by Medlock and Nicholson that another oxidizing substance, Arsenic Acid, was able to convert aniline into a fresh dye called Magenta. Now, Aniline is produced from the hydrocarbon Benzene, one of the light oils obtained from the distillation of tar, so that the base of all the beautiful colours which we see to-day in cloth and silk, etc., the aniline-colours, is that dark repulsive mixture which as we have already observed collects in the wells adjoining the distillation retorts. And the whole industry which has sprung up and has extended into vast proportions is not only one of the greatest triumphs of Applied Chemistry, but it has also rendered the names of those illustrious investigators, who by their skill and patient labour were the founders of an epoch-making industry, for ever memorable. The chemist in his laboratory taking as his working foundation the discoveries of those early pioneers has, by a process of re-arrangement of different atomic groups in the molecular formulæ of artificial products, introduced new compounds with new properties. Thus in the synthetic production of Alizarin, starting with Anthraquinone derived from Anthracene, by treatment with bromine, the result was Alizarin. Or take Aniline and substitute for one of the Hydrogen atoms in it a group of Carbon and Hydrogen atoms and we get Diphenylamine, from which Methyl-violet is obtained. Alizarin dyes, and amongst these is a red-colouring matter, Purpurine, require for the purpose of colouring all kinds of cotton and calico goods certain substances known as Mordants to be incorporated with the material before it is subjected to the dye. These mordants, alumina, iron oxide, etc., form with the dye

insoluble compounds termed Lakes. And the colour of the cloth ultimately depends upon the particular mordant employed. Thus iron oxide produces a violet, and aluminium a characteristic scarlet-red.

Goods dyed in this manner do not lose their colour, and are said to be "fast." But there are some dyes which impart their colouring to cotton fibre directly without a mordant, and these constitute an exceedingly useful series of compounds giving yellow, orange and other colours associated with red. There is also a black which colours direct, a very important substance. These dyes are included in the group known as Azo-dyes, which have their origin in Benzene and Toluene, two of the coal-tar hydrocarbons. Aniline, a close relation of Benzene, is acted on by nitrous acid with the formation of an unstable compound called a "diazo-salt." But on combining with such a substance as Aniline the Diazo-benzene compound forms a stable compound, called Aniline Yellow. This was the starting-point of a whole host of valuable colouring matters which were also the means of disclosing the importance of by-products in the coal-tar industry hitherto unsuspected.

Thus Naphthalene, which is another product of the distillation of coal, became a by-product of importance when it was found that from it and its derivatives a number of important colouring matters like Naphthol Yellow, Manchester Yellow, Fluorescein, Magdala Red and others could be obtained.

An important development of the Dye Industry has lately been announced by the discovery of a new class of "fast" colours which are capable of imparting a wide range of hues to artificial silk. Also, in the case of wool, new dyes of a superior type are the result of recent chemical research. Then, too, for calico-printing a beautiful pink dye has been introduced. Mention also must be made of the discovery by Professor Green of a process for dyeing two colours at the same time.

CHAPTER XXV

RECENT DISCOVERIES AND APPLICATIONS

A CROOKES' tube not only emits Cathode rays consisting of infinitely minute little particles negatively charged called Electrons, but also another type of "positive radiations" known formerly as Canal rays, since they issue forth from behind the cathode if it be pierced with a number of holes (Fig. 120), as was discovered by Goldstein. These rays

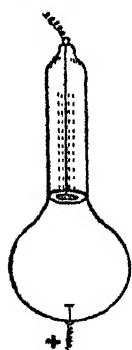


FIG. 120. THE CANAL RAYS

carry a positive charge of electricity whose mass corresponds to that of the Hydrogen atom. Sir J. J. Thomson employing a tube of very narrow bore leading into a larger tube caused the particles to be projected into it behind the cathode, where they were subjected to the influence of magnetic and electric fields. They accordingly were deflected, and the effect was observed on a fluorescent screen and on a photographic plate. A series of curves or parabolic arcs were seen, and light particles were more deflected than heavy ones. A number of gases were subjected to this test, and it was found possible to draw up a kind of spectrum corresponding to the curves, each registering a different atomic weight of the particular element employed. The breadth of the curved lines corresponded to the atomic weights of the elements observed.

The outside curve of all represented Hydrogen, and by comparing all the others in terms of this, some interesting results were observed. The various particles carried unit charges of electricity up to three or more. Hydrogen

Recent Discoveries & Applications 279

revealed itself so often that it seemed to be universally present, also a curious modification or Isotope (*isos*, equal; *topos*, place, Grk.) of the same element, with atomic weight of three, hitherto unknown. So, too, when such a gas as Marsh-gas came to be examined in the tube, mysterious lines appeared suggesting some unknown types. In the light of recent discoveries these researches have a profound importance in their bearing on the constitution of the atom. This form of analysis, too, is exceedingly sensitive, and reveals in elements the presence of new types of atomic states hitherto unsuspected, and all with an exposure of less than one millionth of a second, and working with a quantity of the gas which may be of the order of only $\frac{1}{100}$ of a milligram. Yet with this the atomic weight and charge may be observed with accuracy. Some of the elements, therefore, are not so simple as was formerly thought. The discovery of different atomic states of the same elements—Isotopes as they are called—recorded above, has led to the isolation of many others which, exhibiting the same chemical properties, possess at the same time different atomic weights.

In his Presidential address to the British Association at Edinburgh (of which this is in part a condensation), Sir Edward Thorpe made an interesting allusion to an old theory of Prout that the atom of Hydrogen was the ultimate particle of matter. The conception of a common origin of all material things, involving the unitary nature of matter, is a very old idea. Did not the old alchemists and philosophers hold that the "hyle" of Aristotle was the original primal matter? And in our own time, Crookes advanced a theory that all the elements might be successive condensations of one ultimate entity, which might be Hydrogen. But the results of modern investigation of these profound questions have thrown fresh light upon the old concepts, which have been, as it were, remodelled in terms of the New Knowledge.

The new theory of Matter, which is an extension of Prout's hypothesis, is that all atoms of elements of even atomic number appear to be composed of Helium, while those of elements of odd atomic number are made up of

280 Recent Discoveries & Applications

Helium and Hydrogen with electrons in both cases attached to them.

The atomic numbers refer to the position of the elements when arranged in the order of the numerical value of their atomic weights. Thus we have Hydrogen 1.008, Helium with the next heaviest atom 4.0, Lithium 6.94, and so on right down to Uranium 238.2. If Hydrogen and Helium be omitted in the Periodic Table, as we shall see a little later on, we must add two units to the numbers given.

The isotope of Hydrogen is only one of a number of established facts which support the new theory, the group of three Hydrogen nuclei being perhaps the unknown gas "Nebulium" (Chap. XIX) originally produced in the stars, and which astro-physicists have claimed to be the source of our terrestrial elements. The work of Aston has revealed a number of other elements which appear to be mixtures of these so-called isotopes. Thus Chlorine seems to consist of two substances with atomic weights of thirty-five and thirty-seven, an interesting result of the positive ray method, since all determinations in the ordinary way fix it as 35.46 and not a whole number. Bromine possesses two isotopes, so also Argon; Krypton and Xenon six and five respectively. On the other hand Sulphur is apparently simple, so also Phosphorus. Iodine, too, is a simple element. In the light of all this the Periodic System (Chap. XVII) must be considered afresh. The order of the chemical atomic weights in the table has in addition to it a sequence of atomic numbers which reveal the real progression of the elements. Furthermore, the conception of matter as being composed of atoms of positive and negative electricity, protons and electrons as they are called, "Standard bricks" that Nature employs in her operations of element building," in Dr. Aston's picturesque words, has its bearing also upon the Periodic System.

According to Sir J. J. Thomson we may consider a part of the Periodic Table as exemplified thus:—

1	2	3	4	5	6	7	8
Li	Gl	B	C	N	O	F	Ne

Recent Discoveries & Applications 281

Allowance must be made, as we explained further back, for the omission of Hydrogen and Helium.

The number of electrons in an atom corresponds to the position occupied by an element in the system when arranged in order of its atomic weight. Suppose that the electrons are arranged around a central nucleus of positive electricity on a sphere. The chemical molecule being neutral, only a certain number of electrons can take up their position in equilibrium. Beyond eight they are no longer stable, and the layer breaks up, giving rise to a new arrangement. A new shell would be started outside with a repetition of the old outer layer. And this is very much like what happens in the case of the Periodic System. The element Lithium has one electron in the outer layer, Glucinium two, Boron three, and so on to the end of the octet with Neon eight. The maximum number of available electrons is now reached in the outer layer, and we begin a second group with Sodium nine ($8+1$) with one electron outside, Magnesium ten ($8+2$) with two electrons, Aluminium eleven ($8+3$) with three electrons, and so on. The series then begins again on these lines and continues to the end. We get a periodic recurrence of elements and their properties with an increasing number of electrons up to eight. It is the Law of Octaves expressed in different terms. The valency or atom-binding power of an element is dependent on the same principle. Take Fluorine, for instance; it has seven electrons, and therefore it could take on one more. It is thus univalent. Nitrogen, on the other hand, is trivalent, for it can accommodate three more electrons. Neon has its full number. This explains its inertness and lack of power to form compounds with other elements, if we accept the theory that chemical combination is caused by electrons passing from one layer or outer shell to another. Neon has no electrons to spare. Oxygen is divalent; it has room for two more electrons. Hence it can combine with two atoms of Hydrogen in the familiar way known to us all. It may, however, be sex-valent if we suppose that the six electrons could fill up vacancies in other atoms like its analogue Sulphur, which

282 Recent Discoveries & Applications

combines with six atoms of Fluorine to form a fluoride. When an element appears to have two valencies, one governs "its combination with more negative elements, the other its combination with more positive elements, the sum of the two valencies being eight." And it is in this way that fresh light is being shed upon the question of chemical combination.

The Presidential address at Edinburgh and a lecture at the Royal Institution by Sir J. J. Thomson on "Chemical Combination and the Structure of the Molecule" should be read by any one who is interested in these latest theories of the constitution of Matter and the mechanism of the Atom. I am indebted to both for the brief survey indicated above.

One of the later inventions in science is the Optophone. This ingenious instrument, the invention of Dr. Fournier D'Albe, enables the blind to read printed matter, books, newspapers by producing in a telephone receiver a series of musical notes forming tones or motifs which represent the letters as they are passed over by the instrument in traversing a line of printing. Advantage is taken of the variations in electrical resistance of the element Selenium under the influence of light. Ordinarily, it allows very little current to pass, but when specially prepared it is sensitive to light, and thus its resistance varies according to the quality or intensity of the illumination to which it is subjected. On removing the light it recovers its normal resistance. In the telephone there are variations of the current and so it is possible to hear different notes corresponding to the varying intensities of the rays of light.

Light is caused to fall on a suitable surface of selenium called a "bridge." Suppose that it causes two hundred and fifty-six flashes per second; the current rising and falling at that rate causes the telephone to sing the middle C of the piano. At half the frequency of vibration the note will be an octave lower. Hence any tune can be heard by a proper succession of sets of pulsations of light.

In the Optophone a selenium "bridge" is exposed to

Recent Discoveries & Applications 283

successive pulsations, varying according to the form of the letters traversed in printed type. Each letter has its own note. Printed letters are thus translated into a sound alphabet. The arrangement of the instrument is seen in the annexed figure (Fig. 121).

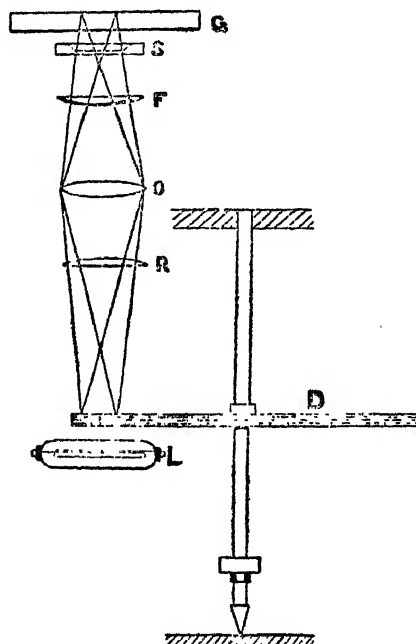


FIG. 121. THE OPTOPHONE

- | | |
|--------------------|--------------------|
| G Glass plate. | O Objective. |
| S Selenium bridge. | R Reflecting lens. |
| F Focussing lens. | D Rotating disc. |
| L Lamp. | |

By permission of Messrs. Barr & Stroud, Ltd.

The printed page face downwards on a glass plate rests on a tablet of porcelain with an aperture permitting the light to pass to the paper. The upper surface is prepared as a "bridge" and is connected up to a battery and telephone. The "bridge" receives light reflected from the

284 Recent Discoveries & Applications

page. The rotating disc is perforated with a number of concentric holes. Underneath is an electric-lamp, the light of which passing through throws by an optical system of lenses an image of the filament on to the paper above. Thus light falls on the print in a series of intermittent luminous dots, is reflected from the type on to the "bridge" and gives rise to a variation of sound in the telephone corresponding to the note of each dot. The printed matter is moved on gradually, and the sounds heard vary according to the change in the shape of the letters. The difficulty of learning to "read" by this instrument is not greater than in the case of the ordinary Morse code. The light on the printed matter forms five spots in line—the Scala, as it is called. Each spot vibrates at a rate corresponding to the



FIG. 122. SCALA PASSING OVER PRINTED LETTERS

By permission of Messrs. Barr & Stroud, Ltd.

number of holes multiplied by the number of revolutions of the disc per second. There are 18 holes in the inner circle, 24, 27, 30 and 36 in the others. If the disc makes $21\frac{1}{2}$ revolutions per second, the second circle of holes will produce 512 pulsations per second, equal to C'. The number of holes given above are in proportion to the vibrations in the notes G, C', D', E', G' (soh, doh, ray, me, soh). In the accompanying illustration (Fig. 122) is seen an enlarged diagram showing the path of the Scala over the printed word "Type." The Optophone is a wonderfully clever application of that curious but interesting element Selenium.

Crookes' protective glass is another valuable invention. The visible spectrum of light is bounded on both sides by regions consisting of vibrations of longer wave-length than the visible red (Infra-red or heat rays) and of shorter wave-length than the visible violet (Ultra-violet or actinic rays) as

Recent Discoveries & Applications 285

seen in the illustration (Fig. 123). A ray of light, consisting as it does of visible and invisible radiations, is capable often of inflicting injury upon that delicate organ, the human eye. And whether people need corrective lenses for sight purposes or not, they do need, often, some protection if exposed to light of unusual brightness or to injurious heat rays. This is especially the case in such industries as Acetylene Welding, where Ultra-violet rays are present in large proportion. So also in glass-working, where the heat rays have been found to be very harmful to the eyes of the operatives. A number of experiments were carried out at home and abroad to combat these evils.

Sir W. Crookes endeavoured to solve the problem in

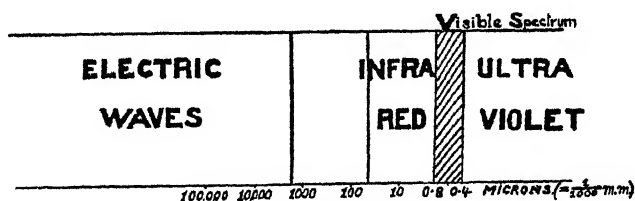


FIG. 123. SPECTRUM OF VISIBLE AND INVISIBLE LIGHT

conjunction with Messrs. Chance Bros., of Smethwick, Birmingham. He found that cataract was prevalent amongst glass-workers. This was not surprising when in one case he found that the operatives were exposed to radiation from a volume of molten glass which covered eighty-two square yards and contained nearly four hundred tons! After experimenting with metallic oxides of Cerium, Cobalt, Chromium, Neodymium, Uranium and others, he succeeded in preparing glasses which by spectroscopic and other tests were found to cut off 90 per cent of the harmful heat rays, were opaque to the invisible Ultra-violet radiations, and were sufficiently free from colour to be scarcely noticeable when used as spectacles. They are adaptable for all requirements, such as exposure to strong sunlight, glare from snow at high altitudes and in the Polar regions, the light of the electric

286 Recent Discoveries & Applications

furnace, molten glass, artificial light. The usual blue or green-tinted glasses are far from satisfactory. They cut off much of the luminous radiation and let the harmful Ultra-violet rays pass. For ordinary work, glasses numbered A and B are generally used. The glass A is very light in colour, cuts off 39.5 per cent and transmits 88 per cent of the heat and light rays respectively, and is practically opaque to the ultra-violet rays. The B glass is especially protective against light of excessive brightness. In both cases Applied Chemistry has conferred yet another boon upon mankind.

Liquid Carbonic Acid-gas has found many applications to-day. The employment of the gas for the purpose of refrigeration and for the manufacture of aerated waters, aerated bread, etc., has led to a large demand. From particulars given by Messrs. Barrett and Elers, Limited, Old Ford, E., it appears that the gas is made by burning coke in furnaces from whence it is passed into two Scrubbers, B J, where it is successively washed by hot water from D and then by cold water flowing over fragments of marble. It now goes into the absorbing towers, E E, containing fragments of coke washed with a stream of Potash Lye from tank F. The lye which is concentrated and enriched by various processes is now boiled off again and the resultant gas passes on to the gas-holder.

The bottles or tubes which are used for storing the Carbonic Acid after careful testing are charged six at a time through tiny spiral pipes which might easily be mistaken for electric wires. Ten tons per day is the average output. The testing proving satisfactory, the tubes are charged with the gas at a pressure of 800 lb. to the square inch, and special precautions are taken in order to prevent interference by unauthorised persons while the tubes are in transit. Part of the process of manufacture is seen depicted in the accompanying diagram (Fig. 124). Enormous quantities of Carbon Dioxide are used to-day for the purpose of making aerated waters. According to particulars kindly given to me by Messrs. Flugel and Company, Limited, Carbonating

Recent Discoveries & Applications 287

Engineers, London, it appears that aerated water machines of all descriptions, from the simple machine for the small household to the bigger ones on a more extended scale, are turned out in large quantities to meet the increasing demand for table waters sparkling with Carbonic Acid. When to this filtration is added, we see at once to what a high pitch the manufacture of aerated waters has been carried to-day, and that Carbon Dioxide, which has not got a particularly good name in many respects, has yet proved itself indispensable in many ways—in the manufacture of mineral waters, the carbonating of beer, sparkling wines, in fire extinguishers and as a refrigerating agent. These are a few examples of its many applications.

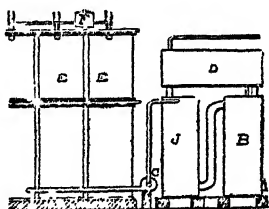


FIG. 124. MANUFACTURE OF CARBON DIOXIDE GAS

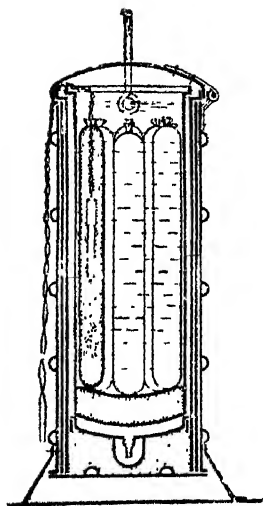
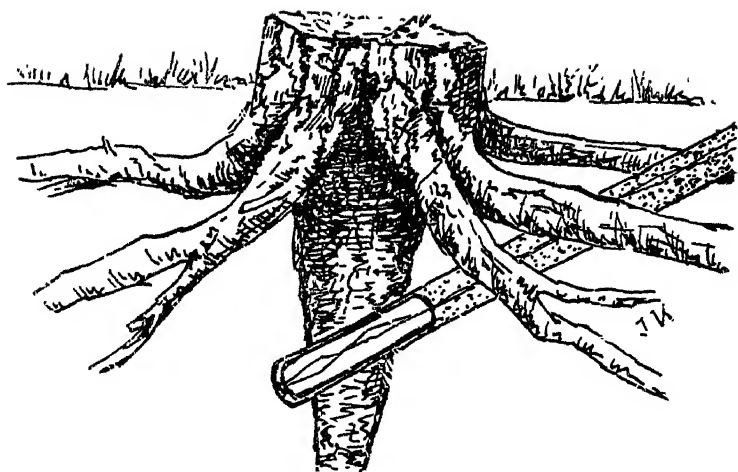
By permission of Messrs. Barrett & Elers, Ltd.

Liquid Air as an Explosive is a curious development of the use of gases for practical work. If some absorbent material such as saw-dust, soot, cork-carbon, etc., is mixed with liquid air it forms an explosive mixture which may be used with good effect for blasting purposes. The finer the absorbent material the greater the force of the explosion. It is estimated that one cubic foot of the liquid (98 per cent Oxygen) evaporates into about 750 cub. ft. of gas, and the time of combustion is very short. An enormous pressure is exerted. The liquid air is transported to the scene of operation in special containers of 1-20 gall. capacity. The cartridges filled with the absorbent ingredients are varied to give different effects comparable with powder, dynamite, etc., and are fired either by a fuse or by a suitable detonator.

288 Recent Discoveries & Applications

When the holes have been prepared, the cartridges fitted with the fuse are placed in a vessel of liquid air in order to absorb the liquid. They are now in an explosive condition but immune against blows. Placed in the bore-hole the fuse is ignited or the electric detonator leads joined up. The shot must be fired within fifteen minutes, since the liquid air evaporates so quickly. In the case, therefore, of a misfire, the cartridges become non-explosive in less than half an hour. During the late war the Germans used liquid air extensively for explosive work, and erected plants for manufacturing the necessary apparatus. Cut off, as they were, by the Allies, they were compelled to fall back upon explosive substances other than those which demanded the employment of glycerine, nitrates, etc., the shortage of which became acute as the war went on. Hence they were driven to the necessity of obtaining explosive materials from their country itself. And this was carried out on quite a large scale.

Oxy-acetylene Welding is an industry which has assumed large dimensions to-day. It is a process for welding and cutting steel and iron by means of the enormous heat value of Acetylene-gas, together with Oxygen which, concentrated by a blow-pipe, forms an easily controlled flame of intense heating powers. Such a value is greatly in excess of that of Hydrogen and ordinary coal-gas. A mixture of 1 to 1.5 volumes of Oxygen to 1 volume of Acetylene yields the best results. The degree of heat produced is very great. That intense and concentrated flame which one sees with its steady white central cone rises to a temperature of not less than 6000° F! Thus a joint can be welded, a fracture repaired, and other metallurgical operations carried out by the localisation of this concentrated heat. And the cost is much less than that of electric welding. Two systems are employed—the High and Low Pressure systems. In the former a cylinder supplies the gas under pressure. In the latter the Acetylene is obtained from a generator, the Oxygen only being used under pressure. Many kinds of metals can be welded, such as steel, wrought-iron, cast-iron,



By permission of the



[Liquid Air Co.]

LIQUID AIR AS AN EXPLOSIVE.

Absorbent cartridges after being placed in a suitable receptacle are covered with liquid air. On removal they are placed under the roots of a tree to blow up the stump.

Recent Discoveries & Applications 289

brass, copper. Union takes place so perfectly that it is impossible to detect the joint when smoothed.

The application of the principle to cutting metals by means of Oxygen alone in the form of a jet or of oxy-acetylene with its higher calorific value is of great service to-day. The jet of flame is able to eat its way as it were through a considerable thickness of metal. The edges are clean and the metal itself is not unduly raised in temperature. The system, dealing as it does with all kinds of repairs and cutting jobs, is especially useful in constricted and awkward situations. Moreover it is applicable to all kinds of work. In the "Acetylene Journal," U.S.A., an instance is given of its adaptability. It was found necessary to remove some concrete which by mistake had been put in during some building operations. Labourers with sledges and drills attacked it, but progress was slow. It was determined to see what could be done with the oxy-acetylene flame. Using a long bushy flame the concrete was heated along the line of the desired fracture; and here the heat was concentrated as much as possible. After a time the concrete yielded to a heavy sledge blow, breaking off as was required in predetermined form and bulk.

At the close of the war, owing to the large amount of salvage work in ships, successful operations were carried out in metal cutting under water. It is a specialised branch demanding skilled and experienced divers thoroughly trained. An interesting article in "Industrial Gases" shows that all cutting under water implies the forcing away of the liquid from the point where the flame comes in contact with the metal. This is effected by surrounding the jet with an air blast. Its pressure increases in proportion to the depth at which work is carried out. One of the great difficulties is to keep the flame alight, and when we reflect that the operator has to contend with currents, employ considerable effort to work the jet in view of the blast of air required to displace the water round the nozzle, to say nothing of the noise and agitation of the water, and the want of visibility, the necessity of employing only trained and

290 Recent Discoveries & Applications

selected men is apparent. The excellent welding schools in various parts of the country give instruction in all the technique of welding to pupils which represent almost every class of mechanic. There, too, they learn all the regulations and precautions so necessary in an industry of this kind as well as the detection of faults, the structure of metal, and the changes which they undergo.

CHAPTER XXVI

FURTHER DEVELOPMENTS OF MODERN RESEARCH

A NUMBER of Rare Metals have interesting applications. Obtained from the ores Scheelite and Wolframite, Tungsten, a metal of high melting-point (5435° F), great ductility and of enormous tensile strength, is used to-day for many purposes, some of which are here enumerated.

The old carbon filament lamps used for electric lighting have during the last few years been largely replaced by others, and notably by those in which the filaments are of drawn tungsten wire which offers a higher resistance to the electric current, and therefore is capable of being raised to a higher state of incandescence. Moreover they are much cheaper, as they take less current. Improved lamps of modern manufacture have now a "life" of over 2000 hours, with an average consumption of half a watt or less per candle power, a watt, it may be remarked, being the power expended when 1 volt causes a current of 1 ampere to flow through a circuit. Tungsten is also used largely for electrical contacts of all kinds, taking the place of the more costly platinum and its alloys. The results are quite satisfactory. In the manufacture of steel Tungsten is used to harden the metal, and such steel was largely used during the late war for the making of high speed machine tools of great hardness and cutting power for munition works, as also for guns and armaments.

An interesting application lies in its use in X-ray work. Under modern conditions and working, as is customary with high electrical tension, consider what happens in a tube. We have a terrific bombardment of the anode by a rain of little particles or projectiles from the cathode, electrons

Further Developments

hurled forth with the fearful velocity of nearly 60,000 miles per second. The energy developed at the point of contact is such that a considerable part is transformed into heat. No ordinary anode, not even one of platinum, will long survive such treatment as this. Disintegration and actual melting of the target takes place, and the tube soon breaks down. But here comes in the value of Tungsten. With its higher melting-point and other advantages it is admirably adapted for X-ray work. We give a diagram (Fig. 125) to illustrate our remarks.

Vanadium is another unfamiliar metal of great hardness and durability, and we need not be surprised to hear that in the manufacture of steel, its addition as an alloy is so marked that very small quantities are sufficient to increase enormously its tensile strength. Hence its use for high speed tools, armour plates, locomotive construction, and in all cases where great strength and resistance to wear and tear are needed.

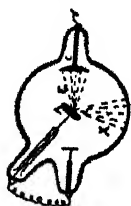


FIG. 125. A
RÖNTGEN TUBE

C Cathode.
E Stream of
electrons.
A Anode.
X Röntgen Rays

Tantalum is another useful metal with a high melting-point and great strength. In electric filament lamps it takes a high position because of its toughness and immunity to vibration. Tantalum lamps, therefore, have come into universal use in shops, factories, offices and for all lighting purposes.

Cobalt, a whitish tenacious metal, has many interesting properties. It imparts to glass a beautiful blue tint, and so-called "Invisible" or "Sympathetic Inks" are made from its salts. Suppose that we write with a dilute solution of the chloride and allow it to dry. If the atmosphere be moist the writing will be of a delicate red in colour. But let the air be dry, or hold the sheet of paper before the fire. A startling change occurs! The water in the little crystals on the paper evaporates and the red colour changes into blue! By and by in a less dry atmosphere the original colour will return. The crystals will have absorbed moisture once more.

Another use of Cobalt is in Electro-plating. Not all electro-plated goods are Silver coated. Some have a film of Nickel on them, and now it has been found possible to substitute for this metal and Silver, the less familiar element Cobalt, which does not tarnish, gives a smooth fine grain, and is a distinct rival of nickel. The metal forms an exceedingly valuable alloy in the turning out of high-class steel. All these metals, together with Manganese and Chromium, which is especially infusible, are now extensively used for this purpose. It is important, however, that the metals should be absolutely pure. Difficulty, very great in the case of Chromium, for instance, stood in the way for a long time. Then a clever application of one of the properties of Aluminium solved the problem. It has been known for a great many years that aluminium has a great affinity for Oxygen, snatching at it, like some greedy child at a cake, seizing upon it with avidity and extracting it from its compounds with metals in the form of Oxides. These oxides are then reduced, they lose their Oxygen, and a pure metal is left behind. In practice this peculiar action of aluminium at first suffered from one serious defect. When the mixture was strongly heated as at first it was thought necessary; the reaction was so violent that a kind of miniature explosion took place in the containing vessel with disastrous results. It was evident that here was a great storehouse of energy if only the reaction could be controlled and kept within bounds. In modern practice this has been found possible by simply firing the mixture by means of a fuse or even a match, without previously heating it. In a few seconds the whole mass becomes incandescent and enormous heat is generated by the reaction, which is of an entirely chemical character. Metals are thus obtained in a pure state, and the process is applicable to a variety of technical purposes where great heat can be generated even in very restricted areas.

The Thermit process yields not only pure metals but also alloys. For welding purposes and the repair of broken machinery, and for all work of this kind, Thermit has proved to be of great use in the industrial world.

Nitrogen is a very useful gas. In the manufacture of Explosives it is used in the form of nitrates, but in times of peace its use is directed largely into more useful channels. Thus for agricultural purposes it is extensively used in the form of nitrogenous manures. Then, too, it helps to produce those strong acids, Sulphuric and Nitric, of which vast quantities are used for industrial purposes. It is estimated that before the late war the consumption of nitrogen manure for agricultural purposes amounted to about one thousand tons daily. Since the war the rate has increased at least 100 per cent. The late Sir W. Crookes once prophesied in an address before the British Association that, unless the land was supplied with more Nitrogen in the form of nitrates, our food resources would dwindle and famine would stare us in the face, since the wheat supply would fail through lack of nitrogenous fertilizers. This dismal prospect, happily, has not been realised, but in view of the dwindling supplies of nitrates from Chile and of native guano, coupled with the fact that with the advance of agriculture the demand for nitrogen products will steadily increase, the question of an adequate supply of Nitrogen in a suitable form has for some time been acute.

That there is an inexhaustible quantity of Nitrogen in the air around us is an admitted fact, but how was it to be utilized? That was the problem. Nature, forestalling man, as she so often does in her inimitable way, wins from the air some of its Nitrogen by means of certain leguminous plants like peas and beans and other members of the Leguminosæ. But not in quite the same way as we saw when studying the action of leaves (Chap. xxiii), and all the wonderful mechanism of those living laboratories for assimilating the Carbonic Acid of the atmosphere by the magic touch of sunlight. We must examine their roots, for there lies the secret of their action. There we find little nodules or swellings where the Nitrogen is cunningly stored by the help of countless little organisms, bacteria as they are known. And when the plant dies the earth is the richer for the

products of decay. Nature has fulfilled her task. Yet we cannot say that here sees the end of her efforts.

In times of thunder when gigantic electric sparks and discharges rupturing and rending the heavens with crashing reverberations are accompanied, as they usually are, by torrential downpours, we see Nature working her schemes to some beneficent end. Minute traces of Nitric Acid and Aminonia are dissolved, and when they reach the earth they form compounds which help to replenish the soil. For slowly but surely this soil will become impoverished, as all who cultivate it know, unless it be enriched from time to time. Nature does not do all. She leads the way and calls upon man to supplement her work. Chemistry, in the wonderful way in which it contributes to-day to the well-being of the human race, has gone far in solving this problem of Nitrogen. Moreover, the processes employed to-day are rendered the more feasible by reason of the cheapness of mechanical and electrical power, speaking in a comparative way. Suppose that we take Calcium Carbide, so much used now for the generation of Acetylene-gas, and cause pure Nitrogen, obtained from liquid air and therefore available in enormous quantities, to act upon it in the intense heat of the electric furnace. The Nitrogen will combine with the Carbide and form a substance called Calcium Cyanamide which, under the trade name of Nitrolim, is found to be an excellent nitrogenous fertilizer, containing more of the gas than even Chile saltpetre.

In Norway, that land of streams and waterfalls, and hence of cheap power, there are a number of companies with extensive plant working out this process on a very large scale, beginning with the production of the Carbide and then passing on to the Cyanamide. It is one of the national industries.

Another method is by the imitation of Nature herself. Nitrogen, in the form of air, is passed through an electric furnace furnished with metal electrodes between which is an arc flame whose temperature exceeds 3000°C . By this means Nitric Oxide is produced, for the Nitrogen, usually

Further Developments

an inert gas, is compelled by this drastic treatment to seize hold upon Oxygen, to become oxidized in fact. It is then converted into a higher oxide which is passed into a series of towers, where water is continually trickling over pieces of quartz. Here a solution of Nitric Acid is formed which is turned into Nitrate of Lime, or as it is called in Norway, Norwegian Salt-petre. The industry has assumed large dimensions in Norway alone. Other countries as well as we ourselves are taking up the matter in earnest.

When Cavendish, many long years ago, described before the Royal Society his method of producing Nitric Acid from the air by the passage through it of electric sparks, he little thought, no doubt, how much the world would owe to his experiments. We give an illustration (Fig. 126) of a simple

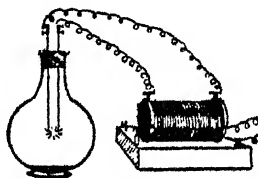


FIG. 126. COMBINING NITROGEN AND OXYGEN BY ELECTRICITY

means of repeating them. A continuous stream of electric sparks from an induction coil passes between the ends of two wires in a glass vessel. After a time red fumes appear of Oxides of Nitrogen, and Ozone can be detected by its peculiar smell. If a little water be shaken about at intervals in the vessel, a weak solution of Nitric Acid may be obtained. But what a contrast these early experiments were to those incandescent furnaces and flaming arcs of electricity to-day, where the heat is so great, so intense, that the most refractory metals are reduced to the molten state with ease, and artificial Nitrogen compounds are formed in large quantities from the ordinary air which we breathe.

Another interesting gas in the light of modern applications is Oxygen. We have seen what an important factor it is in the process of acetylene welding, which is now an

important branch of the metal industry. Let us look at it from another point of view and see the good results attendant on its use in mines and on the front in the late war in rescue work.

The physiological reasons which necessitate its use may be summed up in one word—suffocation or asphyxia. Air containing no Oxygen, or very little, collects in mines when in disuse, in wells and sewers. The development of mining, attended with the dangers of explosions and fire of large dimensions, has shown that air may quickly become unfit for respiration by the presence of irritating gases, sulphur fumes, “after damp” and other evils which demand instant remedial measures if life is to be saved. The value of Oxygen inhalation in all such cases, supplemented as it often is by artificial respiration, whereby the lungs are rhythmically expanded so that the gas may reach the blood, is very great.

Some form of resuscitating and self-contained breathing apparatus must be employed. Messrs. Siebe, Gorman and Co., Ltd., specialists in designing appliances which are extensively used in all kinds of rescue work, and which were employed with signal success at the front during the late war, have very kindly given me particulars of some of their appliances.

The “Proto” self-contained breathing apparatus is designed to supply respirable air independent of any communication with the outer atmosphere for at least two hours at a time. It affords immunity from the most poisonous gases. The wearer breathes the same air over and over again, the Carbonic Acid being absorbed by Sodium Hydrate, and the requisite amount of Oxygen restored from cylinders carried on the back.

In the diagrammatic view of the apparatus (Fig. 127) the action is seen. The wearer exhales through valve S, the air passing down one side of the breathing bag through the caustic soda, and thence up the other side to valve T, to be again inhaled after mixture with fresh Oxygen delivered from the cylinders. A pressure gauge P indicates the quantity

Further Developments

of Oxygen at hand, and the duration of the supply. Z is a saliva trap.

In a previous chapter (Chap. vi) the use of canaries for detecting poisonous air was alluded to. In the annexed diagram (Fig. 128) is seen a portable air "Tester" designed by the same Company to supplement other apparatus in rescue work and to localise poisonous zones. It consists of an aluminium box with mica windows, hinged door, small cylinder of Oxygen at the top forming a handle, and a relief valve and connections. To test any particular air the door is opened and the canary inside is watched. If Carbon Monoxide be present the bird becomes affected.

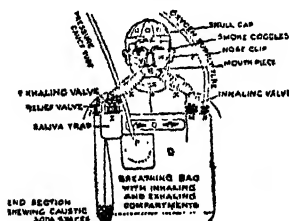


FIG. 127. PROTO APPARATUS

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Siebe, Gorman & Co.

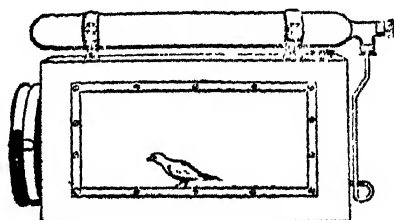


FIG. 128. THE BIRD AIR TESTER

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The door is then shut and Oxygen admitted. The bird revives and is ready for another test.

For remote places where compressed Oxygen cannot be obtained a portable Oxygen making and compressing apparatus is supplied for charging breathing apparatus. A substance called "Oxylithe," prepared in small cakes, is used very much in the same way as Calcium Carbide is for making Acetylene-gas. On coming in contact with water it gives off pure Oxygen which may be collected in bags, or compressed in steel cylinders by a pump. Equipped with such apparatus as we have described, the various rescue brigades of trained workers in different collieries, often engaged under most trying conditions in most unnatural atmospheres, have done yeoman service in rescuing life and rendering pits after explosions and fires free once more from

danger. Everywhere the same story is told of heroic bands of men showing keenness and resource under hazardous conditions. In the salvage of property and the saving of life, in carrying out salvage operations, there would appear to be a sphere of work eminently suitable for self-rescue companies.

Let us now turn to rescue work in the late war. In a paper read before the Institution of Mining Engineers by Lieut. G. F. F. Eager, on the training of officers and men in mine-rescue work, and in one read by Lieut.-Col. D. Dale Logan, D.S.O., M.D., D.P.H., which by the courtesy of the Institution have kindly been placed at my disposal, some most interesting particulars are given of rescue work on the western front.

In the summer of 1915 it was realised for the first time that mining operations would need to be carried on on a far more extended scale in view of the activity of the enemy in mining under our positions. Enormous schemes were developed. The success of the Battle of Messines was due in a great measure to the work carried out by eight Tunnelling Companies for at least fifteen months. The biggest crater at this battle and during the war was in depth of shaft and gallery some 88 ft., while to the centre the distance was 1710 ft. All this work necessitated a large personnel, and by reason of the large quantities of explosives used there was a demand for portable breathing apparatus and men trained in its use. Sets of "Proto" apparatus were sent out to France and systematic training began under the direction of Mr. A. B. Clifford. A mine-rescue school was established which finally was attached to the Second Army Mine Listening School at Proven in connection with the 177th Company R.E. Altogether there were thirty-two Tunnelling Companies on the western front. Each mine-rescue school was responsible to the Controller of Mines for the maintenance of efficiency of the men using Proto apparatus, and returns were rendered weekly by the O.C. each Tunnelling Company, giving particulars of the different sets of appliances—Proto, Novita, Salvus, as supplied by Messrs. Siebe, Gorman and Co.

Recruits for the Second Army School had to pass a rigid medical test before instruction. If a man proved to be unfit in any way he was at once removed from the list of Proto men. Strain, incipient shell-shock, heart weakness, excitability, any symptom, in fact of unfitness, closed many a career in rescue work. The school had a staff and special equipment housed in a hut 90 ft. long, with a span of 16 ft. A large amount of apparatus was kept here, and special instructions regarding its use were issued with every set.

Mine-stretchers or mats with wooden runners designed specially for trench work enabled the rescuers to drag a gassed man along the galleries, and to hoist him up the shafts by the winch-rope.

Artificial respiration was taught, and the administration of Oxygen. Altogether more than two thousand five hundred trainings were given to officers and men, besides lectures to members of the R.A.M.C. on Carbon Monoxide poisoning, and general school lectures on rescue work to all ranks. Certificates of proficiency in the use of apparatus were issued, and the holders were entitled to commence work at once as competent men. Only about 8 per cent failed to pass the qualifying examination. In the detection of Carbon Monoxide, mice were used together with canaries. The little animals, rendered as tame as possible, were carried in a button-up pocket or little pouch. Placed in the hand in tainted air and made to crawl about, a mouse quickly lost the use of its legs and collapsed. And this more rapidly than a bird on its perch.

Altogether by reason of their specialised training, rescue men in France reached a very high degree of reliability and skill. In those strenuous days of high explosives, gas, shot and shell, they proved their worth.

Lieut.-Col. D. Dale Logan points out in his most interesting paper that countless casualties occurred not only from gas-shells, gas-bombs and all the hideous paraphernalia of death-dealing agents introduced by the German Armies, but also from those legitimate weapons in which explosives were used. The casualties in mining alone from gas-

poisoning were very great. At the Battle of Messines nineteen mines of huge dimensions were exploded, requiring more than one million pounds of Ammonal. Carbon Monoxide, as usual, was responsible for most of the gas-poisoning cases in mining. The question of explosives in this connection assumed important dimensions. Gunpowder was very little used, as also gun-cotton, which produced over 40 per cent of the poisonous gas. Most of the high explosives used were compounds of Ammonium and Nitrogen, especially Ammonal, a mixture of T.N.T. or Trinitrotoluene (Chap. xxiv), with Ammonium Nitrate and Aluminium powder mixed with Carbon, supplemented with Blastine and other explosives.

Gas-poisoning was caused in many ways : on the explosion of a mine, the galleries and shafts were filled with the gas. In chalk areas the poisonous gases lingered, and sometimes collected in "pockets." Then there were sudden and unexpected inrushes of gas into galleries, and even into the trenches themselves by way of the shafts. There were also gas explosions in mines, the result of the detonation of high explosives, which on occasions caused grievous loss of life. Numbers of men, however, owed their lives to the rescue-workers, who often conducted their operations under heavy shell fire. In some cases it was necessary to administer Oxygen immediately when men were gassed before they were hoisted up the shaft. The unfortunate men were dragged along the galleries as gently as possible under the circumstances in the stretchers to which they were securely fixed. They were then hoisted to the top.

A graphic description is given of the wonderful effect of Oxygen combined with artificial respiration on cases of gas-poisoning, illustrating the necessity of perseverance even in apparently hopeless conditions. The enemy on one occasion bombarded and raided our trenches and blew up the entrance to the shaft leading to a tunnel in which thirty-six infantry were sheltering. Twenty-five perished from the explosion and gas. Australian rescue-men managed to rescue and resuscitate eleven men, who were entirely

unconscious and heavily gassed. Two appeared hopeless; but after ten hours' work, partly with Oxygen, they had the satisfaction of saving both of these extreme cases! And in countless other cases, under hazardous conditions, the behaviour of the men and the excellence of their work was beyond all praise. There were terrifying experiences when fires broke out in mines and dugouts, spreading, as they often did, with astonishing rapidity, and in the case of that extraordinary incident, unique in the war, when the enemy flooded the coal-field of Béthune with "tear gas" to prevent the French from obtaining coal. This gas, a compound of Chlorine and Picric Acid, was one of the most dangerous employed by the Germans. It was present in enormous quantity. Yet, notwithstanding the arduous nature of the work, for the shafts were deep, the distances to be traversed long, the light defective, the gassing of the collieries, although it resulted in the loss of many valuable lives, did not achieve its object. The enemy as usual failed to realise what men full of resource, devotion to duty and of untiring effort were prepared to do to save a most dangerous situation. The full record of all the work done in those terrible days will probably never be known. That the work of the mine-rescue schools bore abundant fruit is evident to all.

The demand for Oxygen, as we might suppose, was very great, and great credit is due to the British Oxygen Co. for the maintenance of an adequate supply of gas during all those fateful years. Nor was its value entirely medical. Every department of the Government which had to do with war munitions required an ample supply. That the output distributed by the Oxygen Company amounted to upwards of six hundred million cubic feet of gas tells us very plainly the urgent nature of the demand.

We have seen that one of the interesting modern applications of that wonderful gas Ozon lies in its use for ventilating purposes. But there are other interesting applications to-day. Pure water is one of the vital necessities of our modern life. In some cases the

ordinary method of filtration is useless in clearing water of disease-bearing organisms. Ozone destroys all dangerous organisms, and it is not surprising that its use as a water purifier is coming into favour to-day. Moreover, it is claimed that the Ozone treatment results in a general improvement of the natural qualities of the water subjected to the influence of this sterilizing gas. Then, too, Ozone is of great value as an aid to preservation of foods of every description. By reason of its deodorising and antiseptic properties, it has been found useful in maintaining food in storage or factories where the conservation of food is carried on, in a condition fit for human consumption. In brewing, too, which is essentially a chemical process depending on fermentation, the purity and strength of the yeast employed enables those wonderful and complex changes to take place in the yeast cells under the influence of enzymes, with greater uniformity and immunity from contamination.

There are other commercial and industrial applications, also, which depend upon the striking oxidising properties of this curious relation of common Oxygen, this "concentrated Oxygen" gas, which exists naturally in the air we breathe, formed by sunlight rays and electric discharges, by evaporation of salt water and even by the action of certain vegetable products.

It has been shown (Chap. XXIII) that by wonderful and mysterious processes, plants in the living laboratories of their leaves manufacture organic matter by decomposing Carbon Dioxide, an inorganic material, under the magic influence of sunlight and with the help of chlorophyll. The first substance formed is probably Formaldehyde, a compound of Oxygen, Hydrogen and Carbon. This is converted into starch, and by further decomposition into sugar and other carbohydrates, forming thereby the foodstuffs of the plant. Moreover, we know that the particular rays of light which supply the necessary energy to bring about all this wonderful transformation are sifted out by the green colouring matter of the leaves from the remaining ones which are thus excluded.

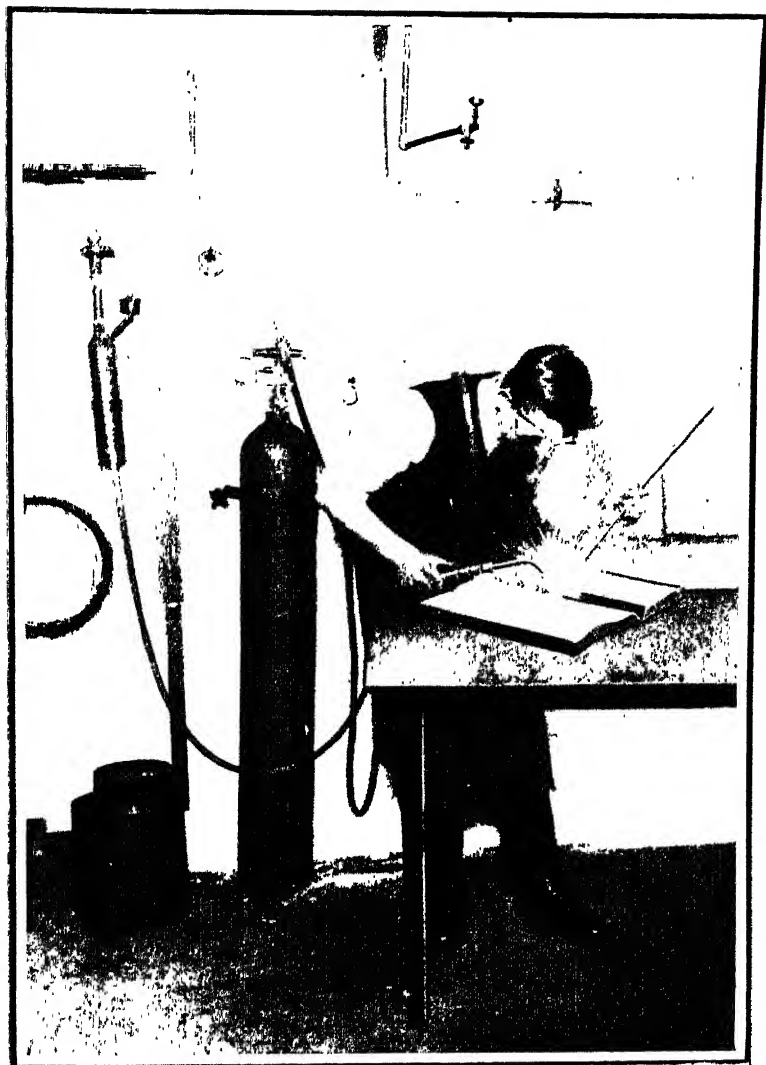
Many have been the attempts in the past to imitate the action of the living plant and to produce by the influence of certain rays of light, red, yellow or even ultra-violet, photo-synthetic organic compounds from inorganic materials, independently of living matter.

The workers in this interesting field of inquiry have been many. To-day we see some of the fruits of their labours. By subjecting in an aqueous solution of Carbon Dioxide salts of Iron and other elements in a colloidal state, to the action of certain rays of light, the synthetic production of Formaldehyde is now an accomplished fact. This opens the door to very great possibilities. Food, perhaps even life itself—what may not be subsequent discoveries? That such a process formed "the first step in the origin of life" by natural means, is the opinion of some of the workers themselves in this branch of research. The physicist has gone far in his attempts to unravel the secrets of the Atom. To-day the chemist, imitating the methods of Nature herself, has advanced another step along the high-road of Chemical Research.

Additional light has lately been shed upon the absorbing question of the inner structure of the Atom by the remarkable experiments of Rutherford and Chadwick. On several occasions allusion has been made in these pages to the modern conception of atomic structure, and we have also seen that the Atom of Radium spontaneously breaks up into helium particles and negative electrons. Was it possible, it was asked, to cause Atoms to disintegrate by artificial means? And, what is the nature of the nucleus, that minute central core of the Atom which is positively charged, and around which the electrons describe their planetary orbits?

In order to obtain any satisfactory answer to these great questions, it was necessary to subject the nucleus itself to a searching examination.

A number of elements such as Nitrogen, Aluminium, Phosphorus and others were exposed to a terrific bombardment by those little particles, the alpha rays, which are



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[The Acetylene Corporation.

CUTTING METAL WITH THE OXY-ACETYLENE FLAME.

The operator with his eyes protected by tinted spectacles is seen cutting through a piece of metal with a blowpipe flame of oxygen and acetylene gases, possessing intense heating properties.

comparatively large and of very great velocity. Millions were rained upon the Nitrogen and other Atoms in the hope of shattering some of them. The results were highly interesting.

Some of the alpha particles did actually collide with the atoms, causing them thereby to break up with the liberation, not of helium, but of Hydrogen.

This is very extraordinary. Atoms of Nitrogen and other elements yield on disruption Hydrogen nuclei which appear to be the ultimate positive units associated with negative electrons. They form the elemental atom. And it is these Hydrogen atoms which give rise to those helium particles which are observed in the spontaneous disintegration of Radium. At all events, the researches alluded to very strongly suggest this.

Index

A

Accumulators, 249, 250
 Acetylene, 223, 232
 Acid, acetic, 227; arsenious, 158;
 carbonic, 243, 245; citric, 232;
 formic, 226; hydriodic, 125;
 hydrobromic, 124; hydrochloric,
 121, 122; hydrofluoric, 126;
 lactic, 234; malic, 232; nitric,
 69, 296; oxalic, 231; phos-
 phoric, 151; picric, 270, 302;
 prussic, 223; pyroligneous, 224;
 sulphuric, 151; sulphurous, 130;
 tartaric, 231
 Acids, 149
 Aerated waters, 247, 287
 Aerophor apparatus, 90
 Air, 60; analysis of, 64; a mixture,
 65
 Alchemists, 13
 Alchymy, 16
 Alcohol, 93, 224, 225, 228, 236, 237;
 absolute, 225
 Aldehyde, 226
 Algæ, 252, 260
 Alizarin, 275
 Alkali, 150
 Alkaloids, 238
 Allotropic carbon, 218; oxygen, 70;
 phosphorus, 128, 132, 133;
 sulphur, 127, 128, 129
 Alpha rays, 81, 173
 Aluminium, 293
 Ammonal, 301
 Ammonia, 72, 115, 116
 Ammonium, 116
 Ampère, 140
 Analysis, chemical, 49, 50; spect-
 rum, 195; positive-ray, 278
 Aniline, 271, 276, 277
 Antimony, 136, 199; detection of,
 136
 Aqua regia, 123
 Aquinum, Thomas of, 18
 Argon, 34, 49, 78, 217

Aristotle, 60
 Arrhenius, 147
 Arsenic, 134; detection of, 135
 Aston, 250
 Atmosphere, 61
 Atoms, 22, 31, 51, 55, 172, 204;
 binding power of, 48, 49
 Atomic number, 150, 201; theory,
 52; weights, 57, 58
 Autome, 217
 Avogadro, 57

B

Bacon, Roger, 17, 18, 19, 203
 Bacteria, 292
 Balkans, 273
 Barium, 171
 Barnard, 213
 Barometer, 62
 Base, 150
 Battery, 138
 Beans, 246
 Becquerel, 170
 Benzene, 232, 271, 273, 277
 Berthelot, 237
 Beryllium, 35
 Beta rays, 81, 174
 Bismuth, 136, 199
 Black, 74
 Bleaching, 120, 130
 Blood, 240, 241; corpuscles of, 241
 Blowpipe, 102
 Bolometer, 200
 Boyle, 55, 63
 Bromine, 124
 Broom-rape, 259
 Brown, 24
 Buddha, 17
 Bunsen burner, 101
 Butter, 247

C

Cailletet, 87
 Calcium, 162, 209
 Calcium Carbide, 232

Calorie, 29
 Camphor, 272
 Canal rays, 278
 Canaries in carbon monoxide, 72, 298
 Capillaries, 95
 Capillary attraction, 95
 Carbohydrates, 106, 245, 246
 Carbon, 96, 97, 98, 105, 218, 233, 242, 252
 Carbon compounds, 218, 219
 Carbon dioxide, 23, 73, 76, 101, 242, 253, 287
 Carbon disulphide, 131
 Carbon monoxide, 71, 76, 77, 268, 298, 300
 Carboxy-hæmoglobin, 77
 Casein, 234, 247
 Cathode rays, 168, 217
 Cavendish, 112, 296
 Cellulose, 237
 Cerium, 249
 Change, chemical, 36; physical, 36
 Charcoal, 221
 Cheese, 234, 247
 China, 17
 Chloral hydrate, 226
 Chlorine, 33, 35, 118, 119, 123, 302
 Chloroform, 223
 Chlorophyll, 254, 255
 Choke-damp, 73, 223
 Chromosphere, 209
 Coal, 222; gas, 265, 266
 Cobalt, 292, 293
 Cocaine, 238
 Cohesion, 23
 Collodion, 269
 Combination, chemical, 43
 Combustion, 104, 105
 Compounds, 33, 37, 41, 42
 Copper, 164, 165
 Cordite, 270
 Corona, 210
 Coronium, 217
 Coumarin, 273
 Crookes, 168, 169, 170, 173, 237, 279, 287, 294
 Crystals, 154; in wireless telegraphy, 158; liquid, 158
 Curie, 81, 170, 171, 175
 Cutting, oxy-acetylene, 289; oxygen, 289
 Cyanogen, 217, 222

D

D'Albe, Dr. Fournier, 282

Dalton, John, 52
 Daniell cell, 142
 Dante, 17
 Davy, Sir H., 33, 116
 Definite proportions, law of, 51
 Deliquescence, 153
 Deslandres, 209
 Dewar, 87, 88, 92, 221, 222
 Dextrin, 235
 Diamond, 157, 220, 225
 Diastase, 256
 Diffusion of gases, 109
 Dispersion, 191
 Dodder, 259
 Doppler's principle, 214
 Double stars, 215
 Dyes, 250, 251, 275; Azo, 277
 Dynamite, 269

E

Efflorescence, 153
 Eggs, 247
 Ehrenhaft, 54
 Elasticity, 27
 Electrolysis, 138; modern theory of, 147
 Electrons, 15, 58, 217, 280, 281
 Electro-plating, 146, 223
 Electroscope, 83
 Elements, 14, 32, 45, 46; classification of, 180; electro-negative, 35; electro-positive, 35
 Elixir of life, 16, 19
 Emanations, 24
 Emanation of Radium, 82, 84, 175
 Energy, 29, 38, 45; conservation of, 45; kinetic, 29; potential, 29
 Enzyme, 224, 256
 Epicurus, 52
 Essences, 273
 Essential oils, 271
 Ether, 23, 225
 Ethereal salts, 228, 274
 Ethylene, 97, 223, 228
 Eudiometer, 113
 Eugenol, 274
 Evershed, 209
 Explosive, liquid air, 287, 288
 Explosives, 267

F

Faraday, 85, 92, 144; law of, 145
 Fats, 246
 Fermentation, 224; acetic, 227
 Filter, colour, 251
 Fish, 247

Fixed-air, 74
 Flames, 95; luminous, 97; non-luminous, 98
 Fleming detector, 158
 Flocculi, 209
 Flour, 246
 Fluorescence, 198
 Fluorine, 125
 Food, 245
 Foot-pounds, 29
 Formalin, 226
 Foucault, 205
 Fraunhofer, 202; lines, 194, 199, 202
 Furnace, electric, 166, 220, 232
 Fusible metal, 137

G

Gamma rays, 81, 175
 Gas poisoning, 301
 Gases, spectra of, 198
 Gay-Lussac, 55, 56
 Geber, 16, 62
 Geiger, 81
 Glass, Crookes', 284, 285
 Glucose, 235, 236
 Glycerine, 260, 270
 Glycerol, 229
 Glycol, 229
 Gold, 165
 Goldstein, 278
 Graeber, 275
 Graphite, 220
 Grating, diffraction, 203
 Gray, 176
 Greeks, 21, 52
 Green, 277
 Gun-cotton, 269; powder, 268

H

Hæmoglobin, 77, 241
 Hale, 208
 Halogens, 125, 181
 Hampson, 82, 88
 Heat, latent, 152
 Helium, 81, 107, 173, 176, 209, 212, 279; spectrum of, 80
 Henry, 170
 Hero, 60
 Herschell, 212
 Huggins, 209, 211, 213, 216
 Humus, 261
 Hydrogen, 23, 35, 36, 106, 213, 219, 233, 279, 280; peroxide, 115; phosphuretted, 134; spectrum of, 198, 211; sulphuretted, 131
 Hyle, 14, 279

I

Iacouse, 273
 India, 17
 Indigo, 275
 Ink, sympathetic, 110, 292
 Infra-red rays, 194, 200
 Inorganic electricity, 215
 Interference, 201
 Iodine, 125, 230
 Iodoform, 223
 Ionization, 170
 Iomene, 271
 Ions, 141, 147, 148
 Iron, 166
 Isomerism, 213
 Isotopes, 279, 280

K

Kelp, 124, 125
 Kieselguhr, 270
 Kirchhoff, 203
 Krypton, 81, 217

L

Lactose, 234, 237
 Lakes, 277
 Lamprey, 200
 Lavoisier, 19, 32, 33, 64, 66, 74, 104
 Lead, 165, 178; sugar of, 165
 Leaves, 255, 256
 Leclanché cell, 141
 Lentils, 246
 Liebermann, 275
 Light, energy of, 201; luminosity curve of, 250; spectrum of, 285
 Lime-light, 99
 Liquefaction of gases, 85
 Liquid, air, 90; argon, 80; carbon dioxide, 286; ethylene, 87; helium, 88; hydrogen, 87; oxygen, 88, 93; sulphur dioxide, 86
 Lithium, 164
 Lucretius, 52
 Lyddite, 270

M

Madder, 275
 Magenta, 276
 Magnesium, 164
 Manures, 262
 Matter, 21; Greek concept of, 32; kinetic theory of, 54
 Mauve, 276

Meat, 247
 Medlock, 276
 Melloni, 199
 Mendeleef, 184, 186
 Menthhol, 238
 Mercury, 34, 35, 93
 Metals, 35, 160, 180, 181; chemical relationship, 181, 182; fatigue of, 162; physical relationship, 180, 182; rare, 291, 292; smell of, 161
 Methane, 100, 223, 267
 Meyer, 184
 Mice in carbon monoxide, 300
 Milk, 247
 Milky Way, 212
 Miller, 211
 Mixtures, 42
 Molecules, 22, 23, 31, 39, 53, 54
 Mordants, 276
 Morphia, 238
 Multiple proportions, law of, 43
 Musk, 24

N

Naphthalene, 275, 277
 Nascent state, 53, 80, 120
 Nature, balance of, 71; unity of, 17
 Nebulae, 215, 216
 Nebulium, 213, 216, 280
 Neon, 49, 83
 Newlands, 183
 Newton, 190, 191, 192
 Nicholson, 216, 276
 Nicotine, 238
 Niton, 84, 175
 Nitro-benzene, 273
 Nitrogen, 64, 68, 219, 253, 294, 295; spectra of, 198
 Nitroglycerine, 269
 Nitrolim, 262, 295
 Nobili, 199
 Noble metals, 123
 Non-metals, 35, 180, 181
 Novae, 213

O

Oatmeal, 246
 Occlusion of gases, 110
 Octaves, law of, 183
 Odorant gas, 267
 Onnes, 88
 Optophone, 282
 Organic chemistry, 218
 Ortho-chromatic plates, 251
 Oxidation, 104, 105

Oxide, 37, 67; nitric, 295; nitrous, 69
 Oxides, acid, 35, 150; basic, 35, 150
 Oxy-acetylene cutting, 289; welding, 288
 Oxygen, 19, 63, 64, 66, 104, 219, 233, 240, 241, 296, 302
 Ozone, 35, 53, 70, 244, 303

P

Panchromatic plates, 251
 Paraffins, 230
 Peas, 246
 Pepsin, 219, 225
 Peptones, 219, 225
 Perfumes, 271
 Periodic system, 34, 184
 Perkin, 276
 Perpetual motion, 30
 Perrin, 54
 Petrol, 230
 Petroleum, 230
 Phenacetin, 238
 Philosopher's stone, 15
 Phlogiston, 19, 104
 Phosphorus, 131
 Photosphere, 207
 Photo-synthesis, 303, 304
 Pictet, 87
 Pitchblende, 171
 Plants, carnivorous, 259; food of, 253; heat of, 257; water, 260
 Plücker tube, 198
 Poison gas, 123
 Polarization, 141
 Polarized light, 157
 Polonium, 171
 Polymerism, 233
 Pope John, 17
 Potassium, 116, 179; bromide, 124; chlorate, 123
 Potatoes, 246
 Priestley, 19, 66
 Prominences, 208, 209
 Proteins, 245
 "Proto" breathing apparatus, 297
 Protons, 280
 Protoplasm, 252
 Protyle, 15
 Prout, 279
 Ptyalin, 225

Q

Quinine, 238

R

Radiant matter, 169
 Radio-activity, 31, 58

Radium, 33, 59, 81, 171; decay, 174; disintegration of, 59, 172, 176; energy of, 172, 176
 Ramsay, 78, 79, 80, 82, 175, 176
 Raphides, 238
 Rare gases, 78
 Rayleigh, 78
 Rennet, 225
 Rescue work with oxygen, 209
 Rice, 246
 Röntgen rays, 198
 Rowland, 207
 Roys, 82
 Rubidium, 179
 Rust, 37, 44, 105
 Rutherford, 81, 82, 175, 176

S

Saccharin, 266
 Safety lamp, 100
 Salts, 40, 116, 151
 Scheele, 30
 Schumann, 199
 Seebeck, 199
 Secchi, 211
 Seidlitz powder, 231
 Selenium, 282
 Silver, 167
 Smyth, Piazza, 212
 Snow crystals, 28
 Soap, 228, 269
 Soddy, 175, 82, 176
 Sodium, 117; D line of, 195
 Soil, 261; sterilization of, 263
 Solder, 167
 Solid, air, 87; carbon dioxide, 87; helium, 88; hydrogen, 88; nitrogen, 87
 Solutions, saturated, 152
 Sparklets, 248
 Spectro-heliograph, 208, 209
 Spectroscope, 193; direct vision, 193
 Spectrum, 191; absorption, 195, 196; bright line, 195, 196, 197; continuous, 195; diffraction, 205; flash, 209; impure, 192; reversal of, 205, 206, 207; tube, 79, 198
 Spinthariscopes, 173
 Spirit, methylated, 225
 Stalactites, 163
 Stalagmites, 163
 Starch, 125, 235, 256
 Stars, 210, 211, 212, 213
 Steel, 166

Strahl, 174
 Strontium, 219
 Sugar, 233, 234, 247
 Sulphur, 127
 Sulphur dioxide, 119
 Sunders, 234, 240
 Sun spot, 210
 Symbiot, 34, 38, 171
 Synthesis, 121
 Synthesis, Catechol, 241; dinitro, 237, 238; chloro, 236, 241; perfume, 234, 235

T

Tantalum, 202
 Tar, 200
 Tarsol, 202
 Tellurium, 285
 Temperature, critical, 86
 Terpene, 232
 Terpinol, 234
 To ting air with camphor, 293; resin, 299
 Thermit, 293
 Thermocouples, 199
 Thomson, J. J., 169, 280, 282
 Thorium, 177, 178; 179, 178
 Thoppe, 279
 Tin, 165
 Toluene, 277
 Tonka bean, 273
 Transmitting power by waves, 25
 Transmutation, 15, 82, 178
 Travers, 82
 Trinitro-toluene, 270
 Tripler, 91, 92
 Tungsten, 291, 292
 Tyndal, 200

U

Ultra-microscope, 54
 Ultra-violet rays, 198, 199
 Unity of Nature, 17
 Uranium, 171, 176, 177; X, 177
 Urea, 219, 233

V

Vacuum vessel, 90
 Valency, 147, 281
 Vanadium, 292
 Vanilla, 273
 Vapour, aqueous, 72

Variable stars, 213
 Ventilation by ozone, 243, 244
 Verdigris, 228
 Vinegar, 227
 Vitamines, 246
 Vogel, 213
 Volt, 140
 Voltmeter, 145, 146
 Volumes, combining, 47; law of, 56

W

Water, 106, 110, 151; composition
 by volume, 112, 113; composition
 by weight, 114; decomposition
 of, 143, 144; distillation of,
 111; filtration of, 111
 Water-gas, 77
 Water of crystallization, 152
 Wave-lengths, 203, 204; numbers,
 212

Wave-transmission of Power, 25
 Waves of light, 189, 190
 Weights, combining, 56; equivalent,
 43
 Welding, oxy-acetylene, 288
 Welsbach mantles, 248
 Wohler, 219, 233

X

X-rays, 291
 Xenon, 83

Y

Yeast, 224

Z

Zero, 91; absolute, 56
 Zinc, 164

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